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ANALYSIS OF TECTONIC FEATURES IN U.S. SOUTHWEST FROM SKYLAB PHOTOGRAPHS

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Contracts NAS2-7523 and NAS9-14440

Prepared for

Dr. Martin Miller
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Skylab photographs (EREP S190A and S190B) were utilized to study faults and tectonic lines in selected areas of U.S. Southwest. Emphasis was placed on elements of the Texas Zone in the Mojave Desert and the tectonic intersection in southern Nevada. Transverse Faults believed to represent the continuation of the Texas Zone were found to be anomalous in strike. This suggests that the Mojave Desert block has rotated counterclockwise as a

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unit with the Sierra Nevada. Left-lateral strike-slip faults in Lake Mead area are interpreted as elements of the Wasatch tectonic zone; their anomalous trend indicates that the Lake Mead area has rotated clockwise with the Colorado Plateau. A tectonic model relating major fault zones to fragmentation and rotation of crustal blocks was developed. Detailed correlation of the high resolution S190B metric camera photographs with U-2 photographs and geologic maps demonstrates the feasibility of utilizing S190B photographs for the identification of geomorphic features associated with recent and active faults and for the assessment of seismic hazards.

PREFACE

a) Objectives

The main objective of this investigation is to determine the utility of EREP photographs (S-190A and S-190B) in identifying tectonic features and regional geologic structures of the U.S. southwest and to interpret their significance to problems of tectonic history. Of particular importance to these problems are regional tectonic lineaments, fault zone continuities and intersections.

In addition to this main objective, we had identified the following lines of investigation among the study objectives:

- Determine whether EREP photographs provide more detailed geomorphic criteria of active or young faults and their relation to the distribution of earthquakes.

- Determine whether EREP photographs provide additional or new insights relating observed structures to mineral deposits.

- Compare EREP and aircraft photographs in terms of ground resolution and information content on geological structures.

b) Scope of Work

The general site of this investigation lies mainly within the southwestern part of the United States. Figures 1, 2 and 3 show the areal coverage of EREP S-190A and S-190B used.

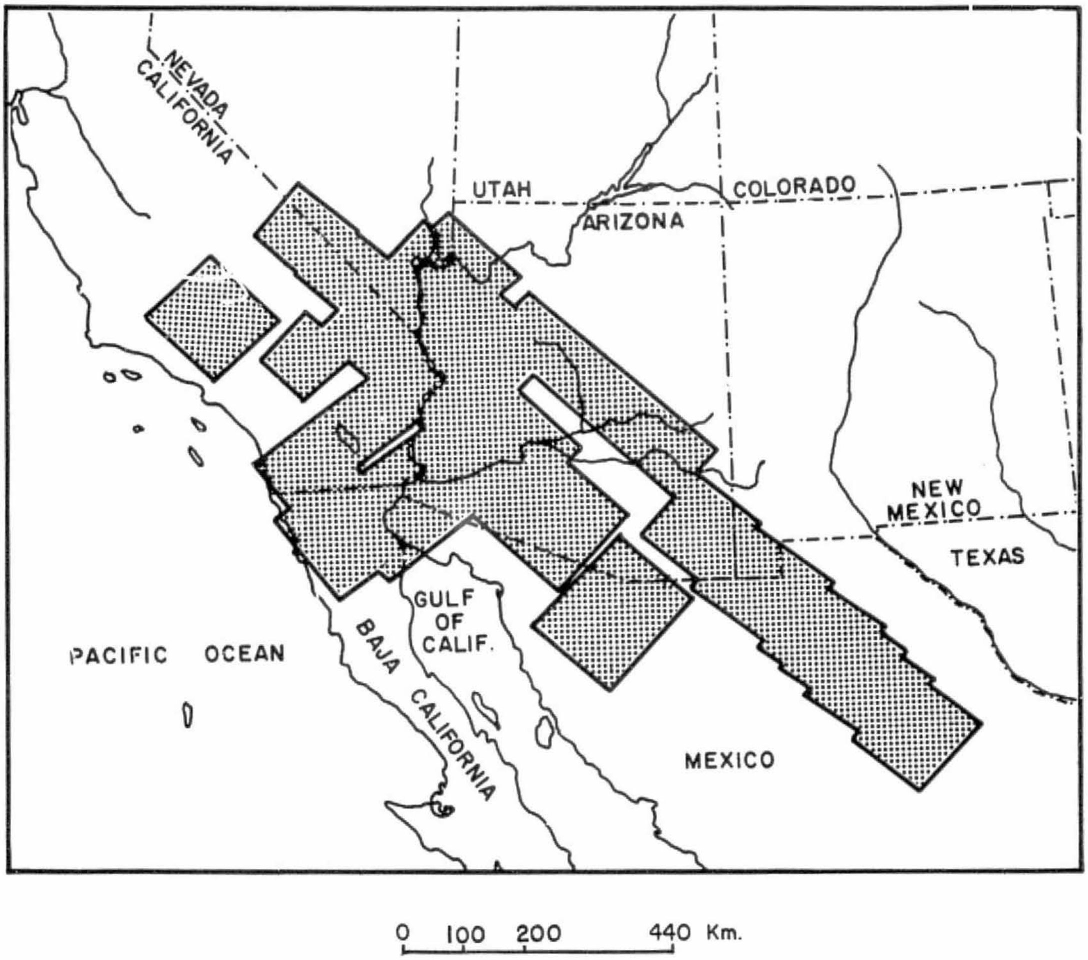

FIGURE 1 GENERAL COVERAGE OF EREP PHOTOGRAPHS USED IN THE STUDY

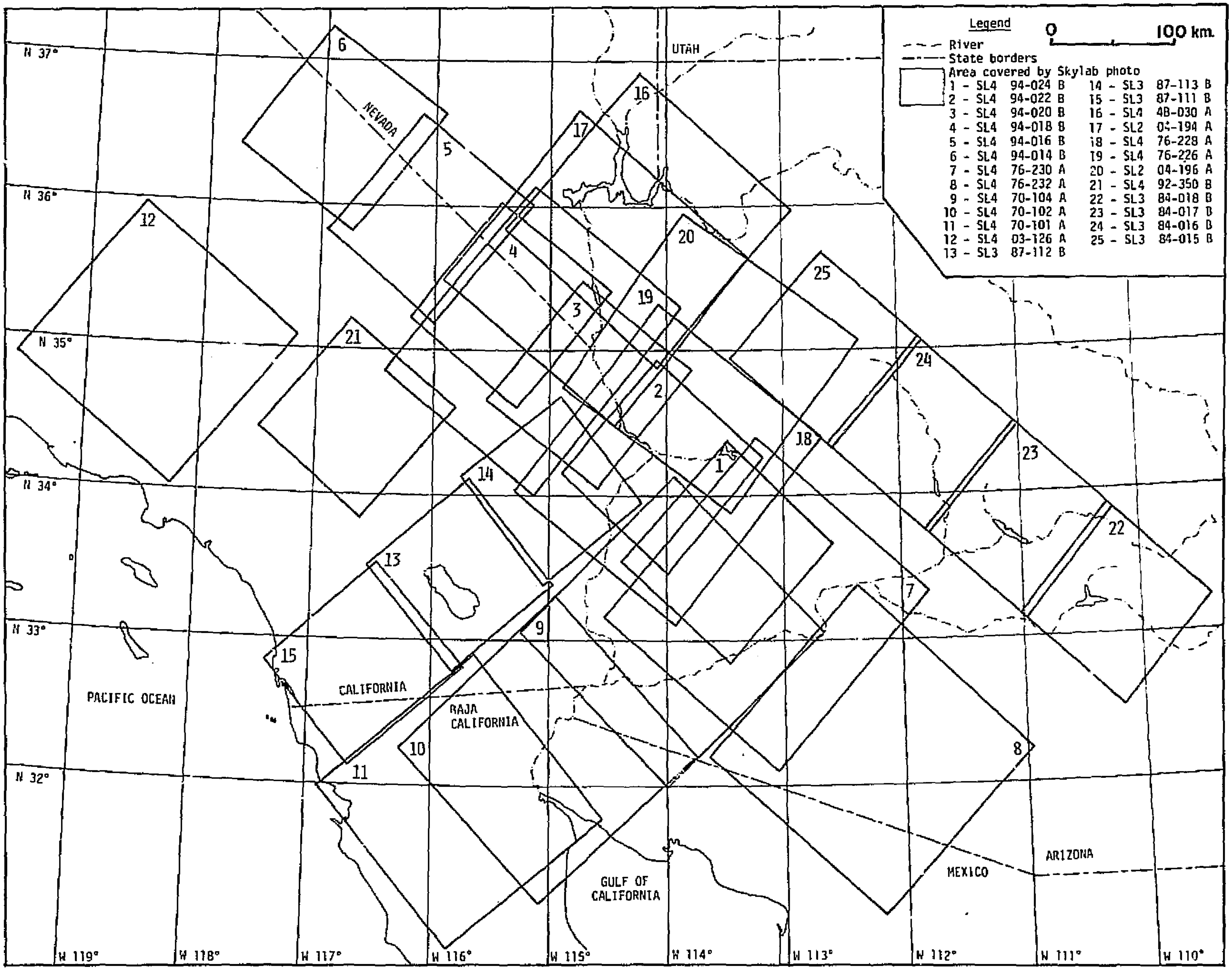

FIGURE 2 INDEX OF EREP PHOTOGRAPHS STUDIED IN CALIFORNIA, NEVADA, AND ARIZONA

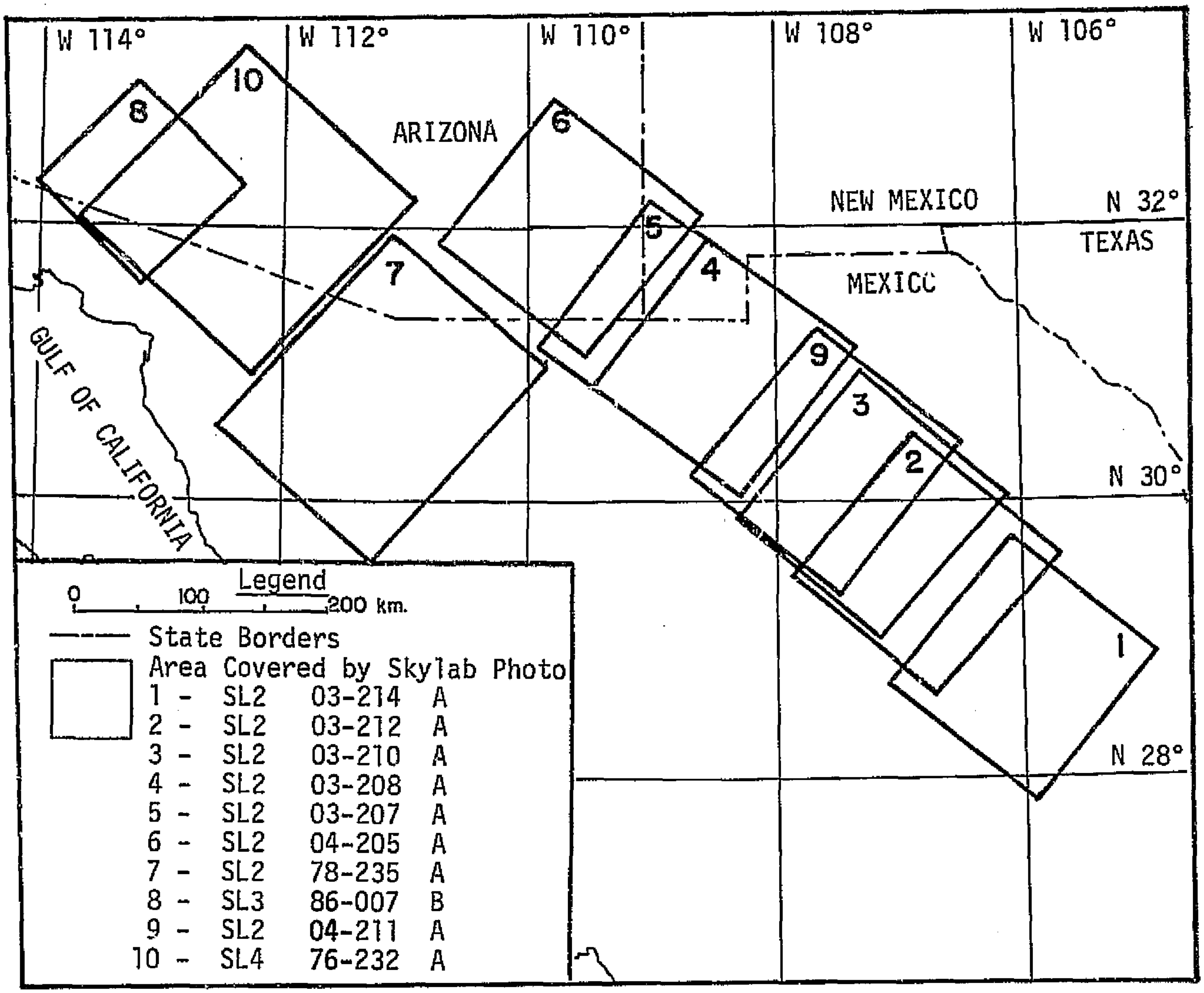

FIGURE 3 INDEX OF EREP PHOTOGRAPHS STUDIED IN MEXICO AND SOUTHERN ARIZONA

In order to achieve the main scientific objective of the investigation, we have been selective in our approach. The writers have, therefore, placed emphasis on the main study objective namely the regional tectonic analysis of lineaments, faults and intersections. One important result of the LANDSAT-1 investigation (Abdel-Gawad and Tubbesing, 1975) has been the identification and mapping of transverse linears related to the Texas Tectonic Zone.

Although the validity of this controversial tectonic feature has, in the writers' opinion, been supported by their LANDSAT-1 study, there remained important questions regarding the projection of the Texas Zone in the Mojave Desert block. The continuity of the Walker Lane shear belt in eastern California was another problem still unanswered by the LANDSAT-1 study. The southern continuation of the Walker Lane shear belt projects also through the eastern part of the Mojave block. It was therefore natural that considerable emphasis was placed in that area during the course of this investigation.

This report contains several maps showing the pattern of faults and linears inferred from EREP photographs. These maps have been assembled from overlays showing the interpretation of individual photographs. In order to maintain a readable size for the final report, only a few examples of the observed features have been selected for illustration.

Further, this report discusses observations on the utility of EREP S-190B photographs in recognizing geomorphic features associated with recent faults. The authors have selected for this discussion one frame covering part of the Western Mojave Desert and San Bernardino Mountains in California.

In addition, the authors compared portions of that frame to U-2 photographs in an attempt to study the fracture pattern and estimate the ground resolution. Ground truth observations and measurements were made during field trips.

Several other avenues of investigation were briefly pursued and then abandoned mainly in order to focus our efforts on the principal study objective.

c) Summary and Conclusions

Interpretation of Skylab photographs (S 190 A and S 190 B) provided strong evidence supporting the validity of the Texas Tectonic Zone. Both LANDSAT-1 and EREP photographs show that the Texas Zone is an illdefined belt some 2000 km long, 250 km wide extending from the Gulf of Mexico to the Transverse Ranges of California. The regional trend of the belt is N 60°W. It is characterized by a system of discontinuous linears with strikes ranging from nearly east-west to N 55°W. The linears range from subtle and vague features to structural alignments of fault blocks and drainage lines to very distinct faults, fractures and deformation zones.

This study supports Schmitt's (1964) interpretation of the Texas Zone as a major belt of left-lateral shear. The authors add to Schmitt's arguments the apparent 500 km offset of the Paleozoic Millard belt of Nevada from its continuation in Sonora, Mexico.

From a plate tectonic view point the Texas, Parras, and Central American Shears appear to be elements of the very broad deformation marking the differential movements of the North American and South American plates. The left-lateral offset of the two continents seems to be distributed across Central America, Mexico, and southwestern United States.

The Texas Zone projects into the Mojave Desert block. Here, transverse faults believed to represent the continuation of the Texas Zone have distinctly anomalous strikes ranging from east - west to east - northeast. The transverse faults of the Mojave Desert block appear to be generally older than the northwest trending faults which parallel the San Andreas system. We interpret the anomalous strike of the Texas Zone in the Mojave Desert as indicating counterclockwise rotation of the Mojave block, together with the Sierra Nevada block, about 25° and possibly more.

The rotation of the Mojave - Sierra Nevada blocks may have caused a change in the orientation of the Garlock fault and its offset towards the northwest from an eastward extension in the

Lake Havasu area. The offset and rotation is conjectured to have taken place along a fault marking the eastern structural boundary of the Mojave block.

The Eastern Mojave Boundary fault refers to a major break extending from the southern end of the Death Valley to the Colorado River bend south of Lake Havasu. It is one of several en echelon faults forming an extension of the Walker Lane shear belt which separates the greater Sierra Nevada block from the Basin - Range province.

The term Sierra Nevada here refers to the greater block which includes Argus, Slate, Panamint and Amargosa Ranges. The right-lateral Walker Lane shear belt includes the following faults: Walker Lane, Furnace Creek, Las Vegas, Stewart Valley which runs parallel to the Nevada - California border.

The authors' proposal that the Mojave block has rotated counterclockwise is consistent with Garfunkel (1974). Hamilton and Meyers (1964) suggested that the Sierra Nevada has rotated in a similar direction. This concept implies that entire volcanic region of the U.S. northwest (Columbia Plateau, Cascades, Snake River) and the Basin and Range province in Nevada are spreading centers intruded with new crust. Reconstruction of the entire massif consisting of Klamath Mountain, Sierra Nevada, and Mojave blocks by clockwise rotation as a unit would bring the massif nearly in alignment with the Idaho Batholith. The entire

Mesozoic intrusive system would then form a broad arch extending from Idaho to Baja California.

Detailed correlation of one EREP S-190B frame covering the western part of the Mojave Desert with geologic and fault maps has shown that the image quality and ground resolution are sufficient to identify many geomorphologic features associated with recent faulting.

Enlargements of the same S-190B frame were compared to U-2 color infrared photographs obtained by an RC-10 metric camara. In spite of the inferior ground resolution of the S-190B photograph, we found that both image quality and resolution allow accurate mapping of faults. Ground truth observations indicate that under favorable conditions and high contrast surroundings, some roads approximately 6 meters wide could be visually detected.

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LIST OF ILLUSTRATIONS

TEXAS TECTONIC ZONE (LINEAMENT)

The southern part of the North American Cordillera is interrupted by two transverse structural trends: Texas and Parras. The Texas Zone was originally described as a lineament by Hill (1902), and was redefined by Schmitt (1966) as a transverse structural zone trending N75°W from the edge of the Gulf of Mexico to the Santa Rosa Island, California. It coincides with a hiatus in the topography and with chaotic structural blocks and may represent the roots of a major worn down mountain range. Albritton and Smith (1956) suggested a possible Precambrian age. Kellum _et al_. (1936) pointed out that the Texas Zone coincides with a late Jurassic shore line. The economic significance of the Texas Zone was discussed by Wertz (1970), Guilbert and Sumner (1968), and Mayo (1958). This major tectonic feature of the U.S. southwest has been highly controversial (Baker, 1934;Moody and Hill, 1956;Mayo, 1958; Griswald, 1961; Muehlberger, 1965;Abdel-Gawad and Tubbesing, 1974, 1975). Lowman and Tiedemann (1971) gave a good summary of conflicting views and tentatively concluded from their analysis of Gemini photographs that the Texas Lineament is not a single fault or even a discrete fault zone, but rather appears to be a broad belt of folds and dip - slip faults related to the Mesozoic Mexican geosyncline. One objective of this study and our

LANDSAT-1 investigation, (Abdel-Gawad and Tubbesing, 1975) was to examine geological structures, in the space imagery, related to the Texas Zone. Many linears of Texas trend have been observed in Gemini and Apollo photographs over southern California, southern Arizona, New Mexico and adjacent parts of Mexico. However, the obliqueness of Gemini and Apollo photographs caused some uncertainty regarding the orientation and continuity of those structures.

The writers utilized LANDSAT-1 and EREP S-190 photographs first phase of this investigation to map outstanding linear features within an extensive area north of 24°N in Mexico and across the border into the United States. The map shown in Fig. 4 (Abdel-Gawad and Tubbesing, 1974, 1975) was compiled from image interpretation overlays of LANDSAT-1 and some EREP imagery which was available prior to the second phase of this investigation. The initial mapping of linears was made on imagery overlays at a scale of approx. 1:1,000,000 and then compiled on a base map (scale 1:2,500,000) using a Bausch and Lomb Zoom Transfer Scope.

Figure 4 shows that transverse linears indeed affect a broad area of the U.S. southwest and northern Mexico. Within this broad distribution, however, certain zones of linears are characterized by regional continuity. A remarkable example is the Phoenix - Nueva Rosita Zone which extends from Lake Havasu

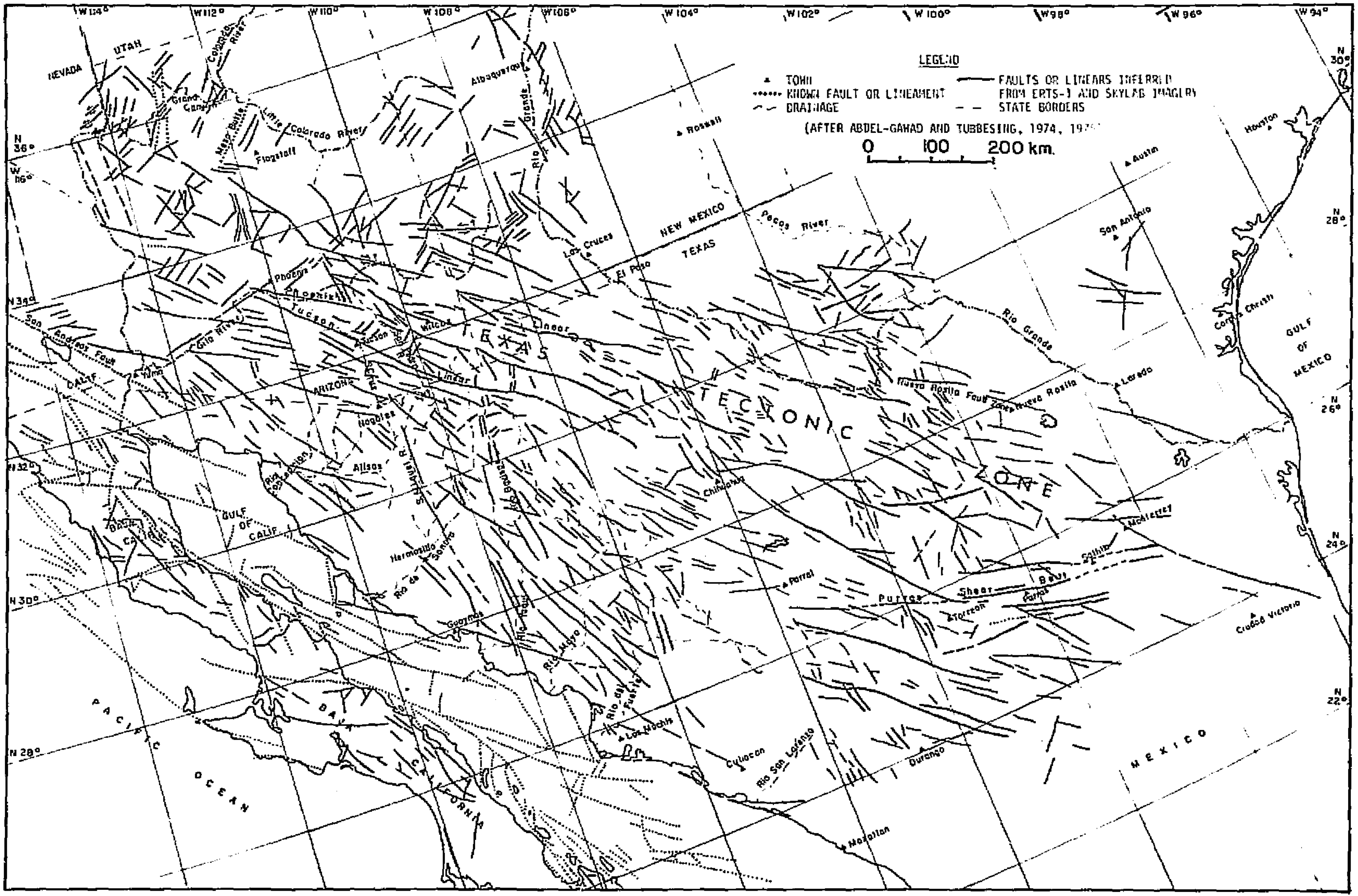


FIGURE 4 LINEAMENTS IN NORTHERN MEXICO AND U.S. SOUTHWEST INFERRED FROM LANDSAT-1 AND SKYLAB IMAGERY

area east of the Colorado River through the Gila River bend near Phoenix and through northern Chihuahua and along Nueva Rosita Fault Zone in Mexico. West of the Colorado River the transverse linears are anomalous in trend and are interrupted by the San Andreas fault system. On the southeast end the Phoenix-Nueva Rosita Zone becomes unrecognizable through the Late Tertiary and Quaternary sedimentary cover which border the Gulf of Mexico.

Following this regional study of Texas Zone linears the writers utilized EREP S-190 A and S-190 B photographs to investigate selected areas in more detail. Figures 5A and 5B have been compiled from interpretation overlays of skylab photographs covering areas shown in Figure 1. A discussion of selected examples follows:

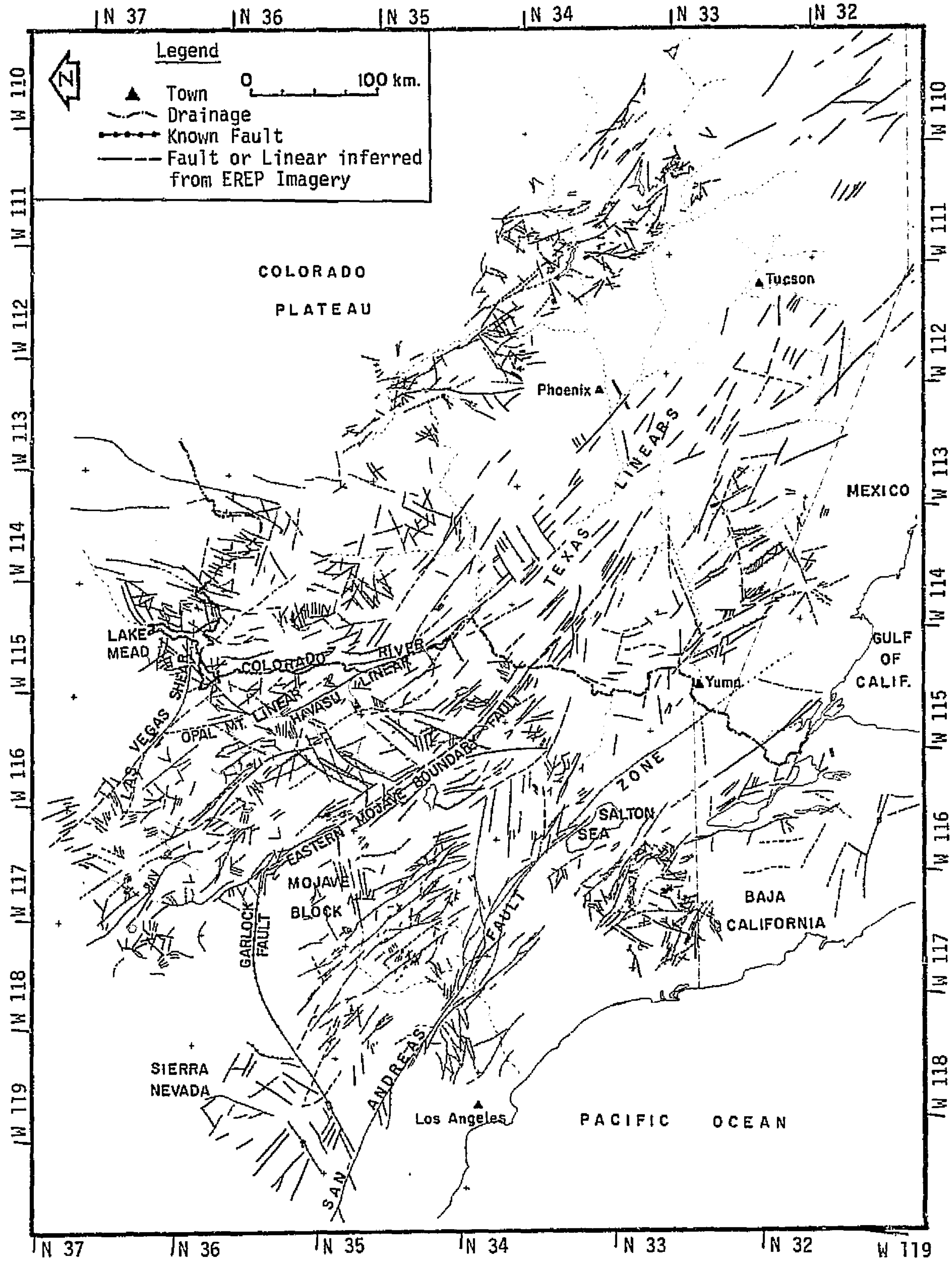


FIGURE 5A FAULT AND LINEAMENT MAP COMPILED FROM EREP PHOTOGRAPHS

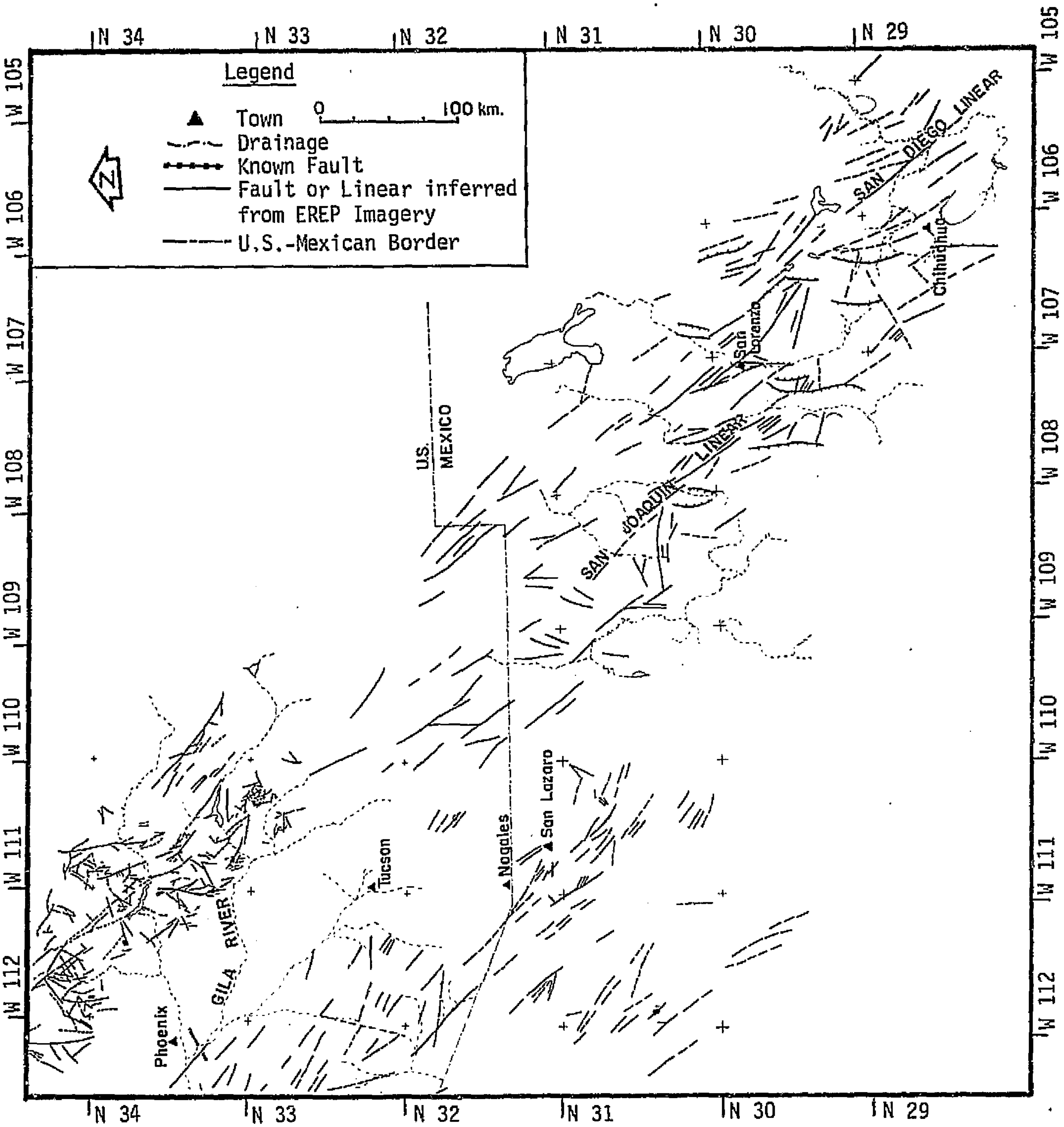


FIGURE 5B FAULT AND LINEAMENT MAP COMPILED FROM EREP PHOTOGRAPHS

Structural Linears in Chihuahua, Mexico

In Chihuahua region of northern Mexico transverse linears are observed across the northern part of Sierra Madre Occidental. We studied a strip of overlapping S 190 A photographs extending from southeastern Arizona to the vicinity of Chihuahua City, Mexico. Significant examples of these linears, which we inferred from the photographs named after towns or cities in their vicinity are described below.

Scene SL2-03-214 (Figures 6 and 7) shows the northeastern part of Sierra Madre Occidental and the city of Chihuahua. A major linear structure (San Diego) extends from the vicinity of San Diego, Chihuahua State, west - northwestward to southwestern New Mexico where prominent lineations are observed along Little Hatchet and Big Hatchet Mountains.

Scene SL2-03-212 (Figures 8 and 9) show pronounced structural breaks across Sierra de la Tunas and Sierra del Nido, Mexico. The San Joaquin linear, appears to control the northern side of Sierra de la Catarena and the mountain ranges west of it. A map showing significant linear structures in northern Mexico is shown in Figure 5B. The linears affect terrain covered by Middle Cenozoic volcanic rocks of the Sierra Madre Occidental which seems to indicate recurrence of faulting along the Texas Shear in post-Middle Cenozoic time or that Basin and Range faulting partly took place along some Texas strands.

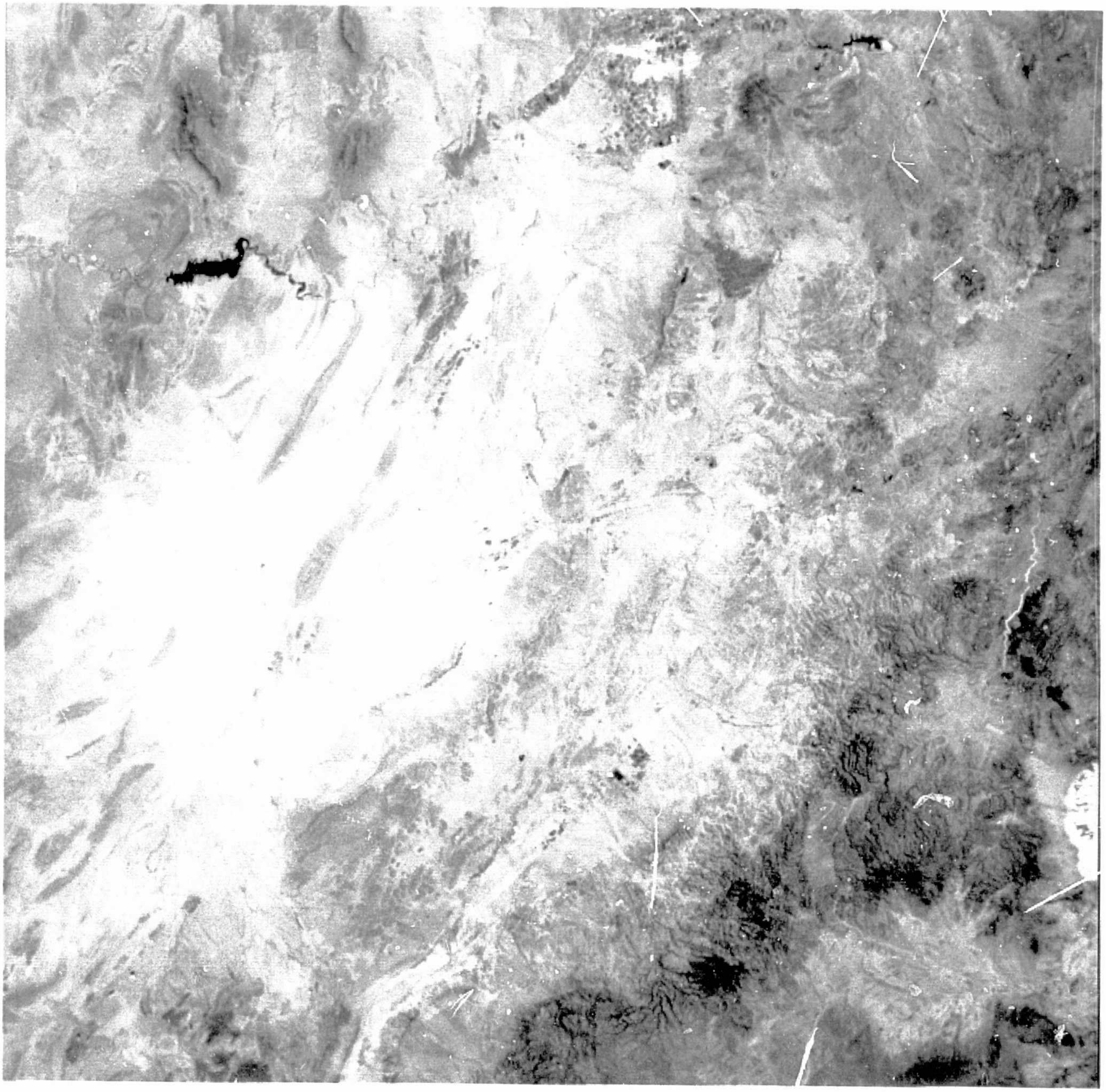


FIGURE 6 EREP SCENE SL2-03-214, CHIHUAHUA, MEXICO

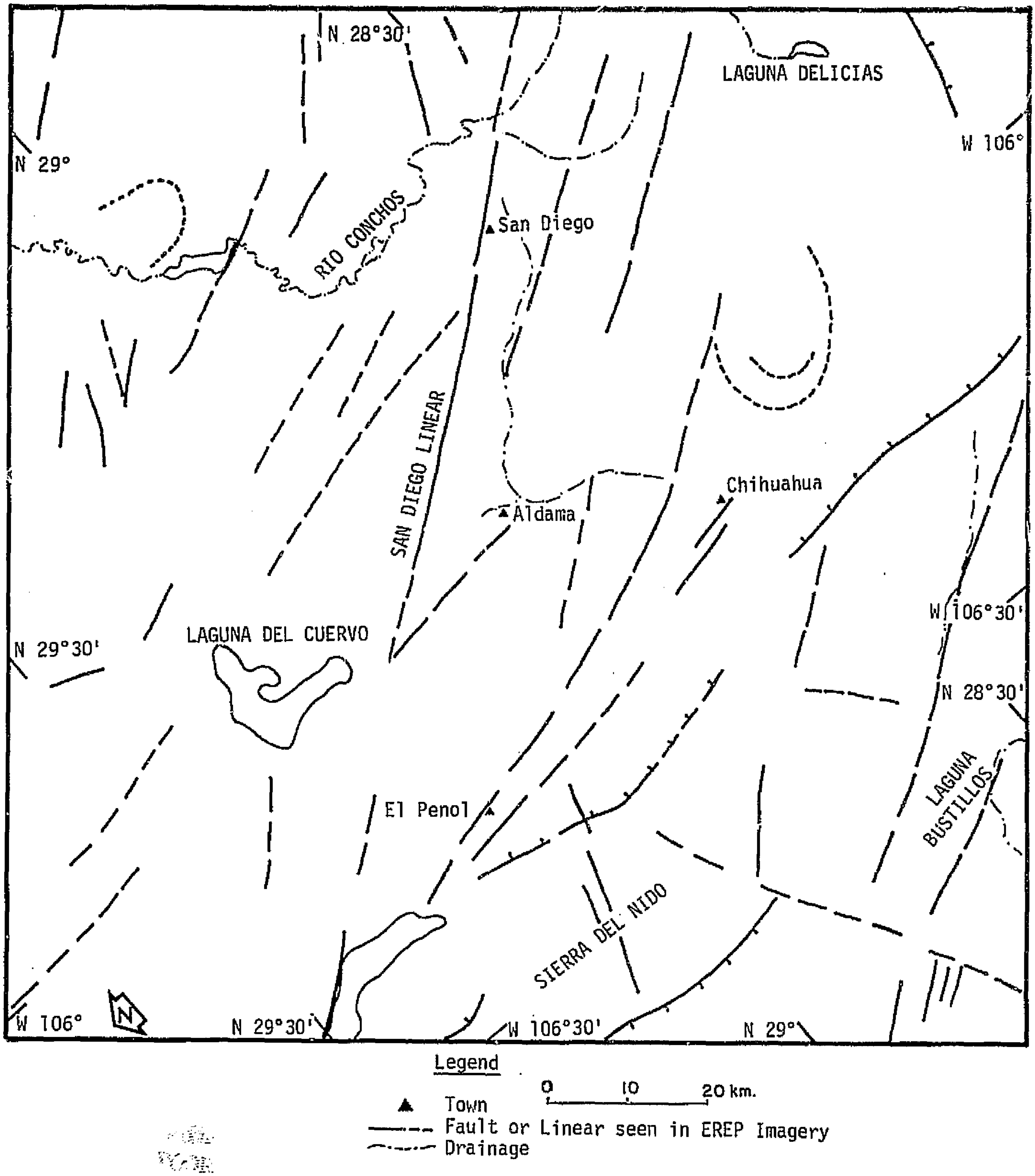


FIGURE 7 LINEAR STRUCTURES INFERRED FROM SCENE SL2-03-214

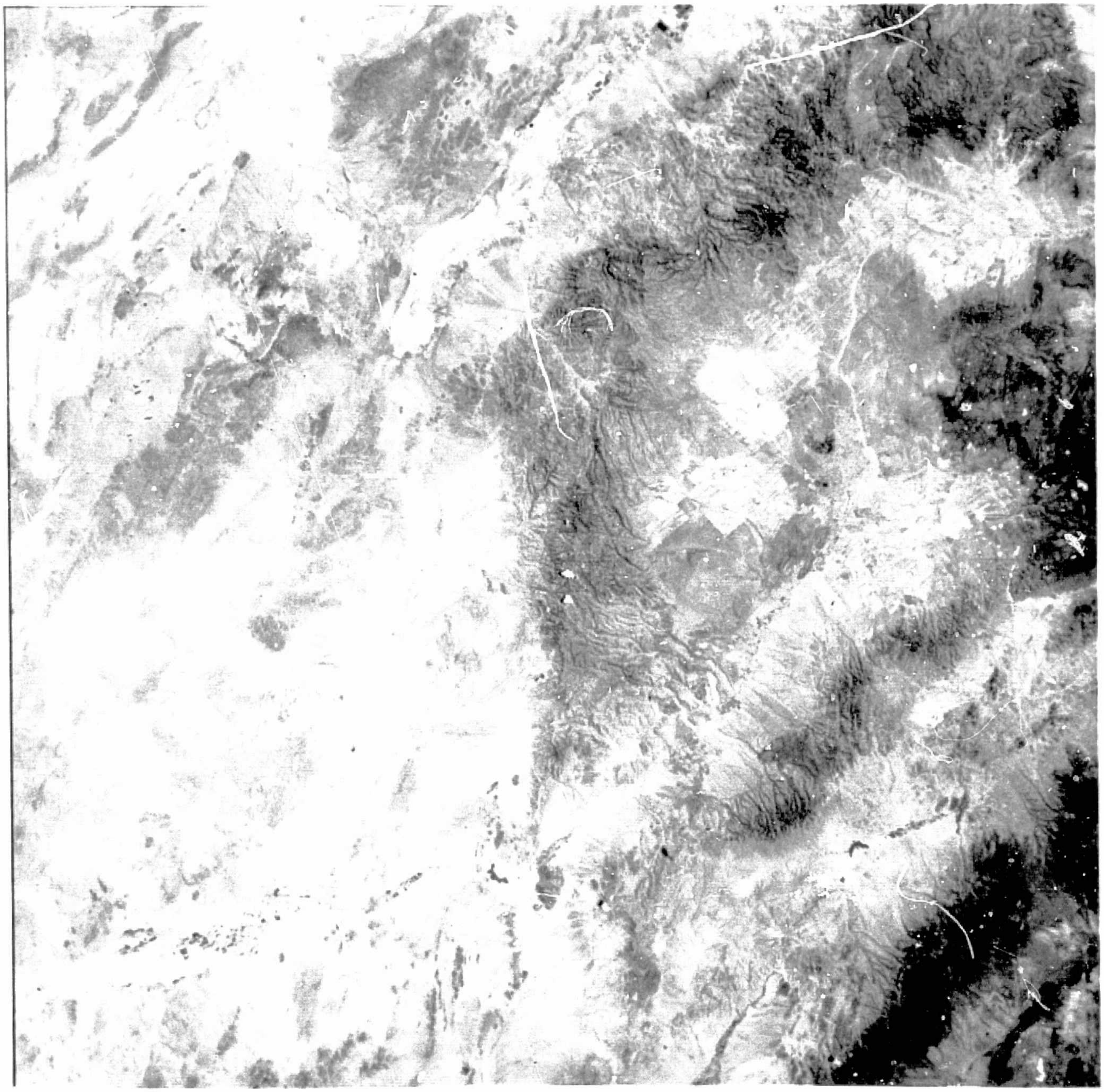
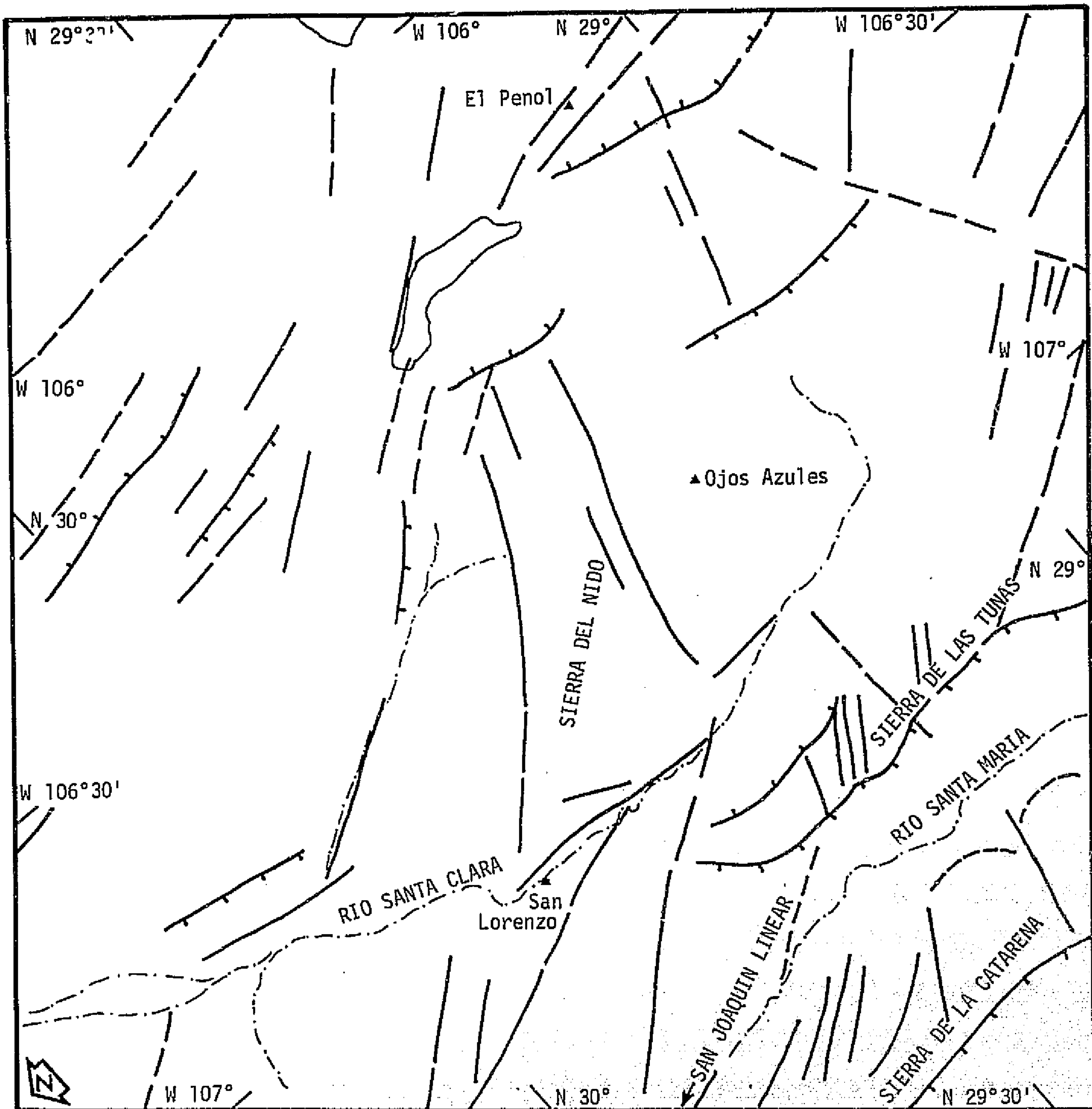


FIGURE 8 EREP SCENE SL2-03-212, SIERRA DE LAS TUNAS AND SIERRA DEL NIDO, MEXICO



Legend

0 10 20 km.

▲ Town

——— Fault or Linear seen in EREP Imagery

—·—·— Drainage

FIGURE 9 MAJOR STRUCTURES INFERRED FROM SCENE SL2-03-212

Structural Linears in Southern Arizona and New Mexico

EREP photographs show that transverse faults are pervasive across much of southern Arizona and New Mexico. They profoundly affect the structures of Dos Cabezas, Big Hatchet, Chiricahua, Animas, and Huachuca Mountains and are particularly prominent across the southern part of Mule Mountains in the vicinity of Bisbee, Arizona. These observations are consistent with field studies. Erickson (1968) reported that Dos Cabezas Mountains were broken along at least two west - northwest trending faults after the deposition of the Bisbee Group indicating early Tertiary (Laramide) age. Chiricahua and Animas Mountains consist largely of Tertiary acidic volcanic rocks. According to Drewes and Finnell, (1968), many Laramide granitic stocks are emplaced along structures of the Texas Zone. West - northwest trending faults cut across the southern part of Whetstone Mountains. At least three parallel faults are observed cutting across sedimentary rocks ranging from Devonian - Pennsylvanian in age. Field observations and correlation with geological maps (Wilson, Moore and Cooper, 1969; Hayes and Raup, 1968) suggests approximately 3 km strike slip displacement on each strand. The cumulative offset between the Whetstone Mountains and the Mustang Mountains to the south exceeds 10 kilometers. Graybeal (1962) reported about 4 km right - lateral offset on the Mescal Creek fault which separates the Whetstone Mountains from the southern

Whetstone Mountains. Although these faults are parallel to the Texas trend the sense of displacement is opposite the regional left - lateral offset conjectured along the Texas Shear.

West of Nogales the Pajarito Mountains are cut by prominent faults similar to those affecting the mountain ranges in the northwestern part of Sierra Madre Occidental. Transverse faults are observed south of Nogales and San Lazaro and in the vicinity of Caborca, Mexico (Figures 10 and 11). These faults affect rock units ranging from Precambrian and Paleozoic sedimentary and metamorphic rocks to Middle Cenozoic volcanics.

This region of southern Arizona and adjacent areas in Mexico may be tectonically active. We have observed in the Skylab photograph (Figures 10 and 11) two northwest trending faults, running oblique to the Texas Zone between San Lazaro and Nogales which appear to cut pediment alluvium and disrupt drainage lines. The seismicity of this region was also evidenced by the 1887 Great Sonoran earthquake which created 7.8 meter-high scarps in area 100 km south of the international border and was felt as far north as Phoenix (Haynes, 1968, p. 93 quoting Richter, 1958, p. 594). A report on the geology of Pena Blanca, Walker Canyon and Pajarito Mountain area of Santa Cruz County, Arizona by Nelson (1968, p. 177-178) stated that the area lies within a zone of recurrent breakage as all the rocks exposed have suffered some degree of fracturing and movement. Nelson also stated that very

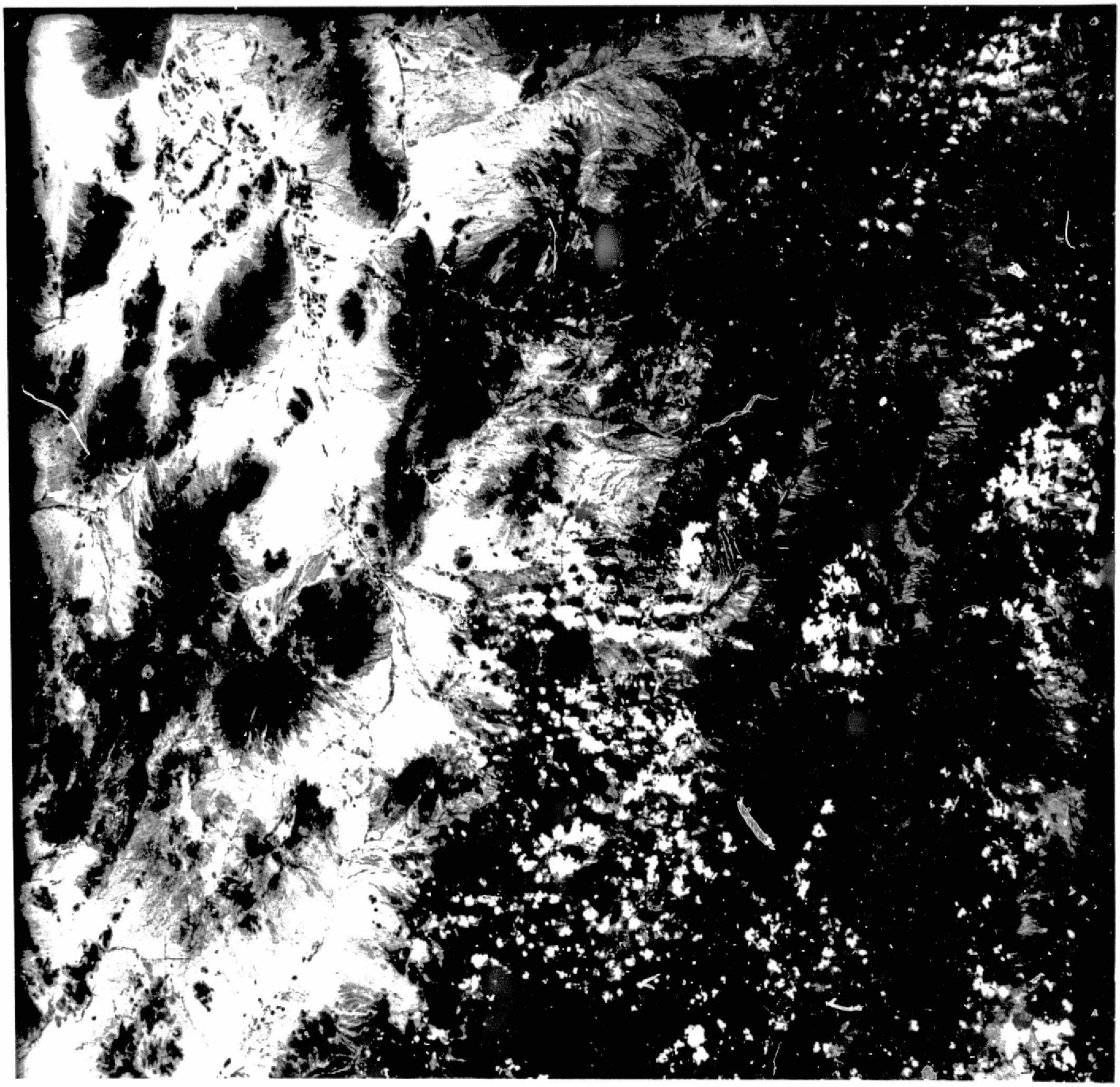
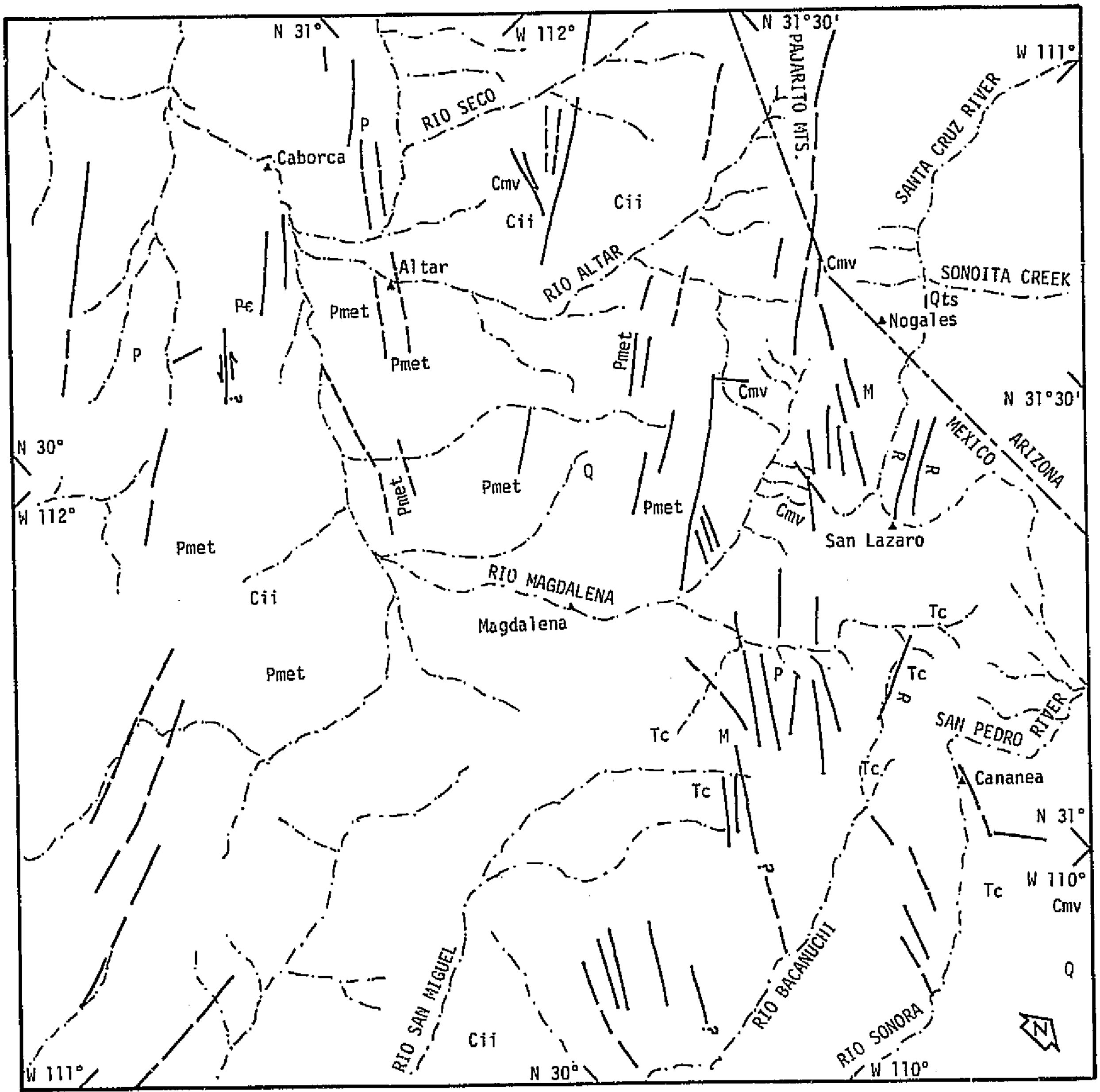


FIGURE 10 EREP SCENE SL2-78-235, SOUTH OF NOGALES



Legend

0 50 km.

▲ Town
Drainage
R Fault, Recent movement (R).
U.S. - Mexican Border

Q - Quaternary Alluvium
Tc - Upper Tertiary Continental Deposits
Cmv - Middle Cenozoic Volcanics
Cii - Lower Cenozoic Intrusives
M - Mesozoic, undifferentiated
P - Paleozoic, undifferentiated
Pmet - Paleozoic Metamorphic Rocks
Pc - Precambrian Igneous and Metamorphic Rocks

FIGURE 11 TRANSVERSE FAULTS INFERRED FROM EREP SCENE SL2-78-235, SOUTH OF NOGALES

steep or almost vertical faults trending N 70°W to N 80°W form one of the largest zones bounding the north flank of the Pajarito Mountains.

Transverse faults cut across the north - south trending Baboquivari Mountains which consist largely of Mesozoic and Tertiary granitic rocks intruded into phyllites and schists.

In southwestern Arizona strands of transverse linears are observed within a belt some 100 km wide passing between Phoenix and Ajo, Arizona. Some linear structures in this belt are shown in Figures 12 and 13.

They affect rocks ranging in age from Precambrian to Quaternary. Examples:

Precambrian granites and gneisses of White Tank Mountains; Createaceous andesitic flows and tuffs in Big Horn and Saucede Mountains; Cretaceous and early Tertiary (Laramide) granitic intrusives in Eagle Tail Mountains and White Tank Mountains; Tertiary (?) intermediate volcanic rocks on the southern side of Crater Mountains; Tertiary intermediate and basic volcanics in Sand Tank Mountains; Quaternary basalts in Tank Mountains.

Examples of linear drainage lines assuming transverse trends are Gu Oidak-Vamori wash and parts of San Simon Wash where it runs close to the Arizona-Mexico border.

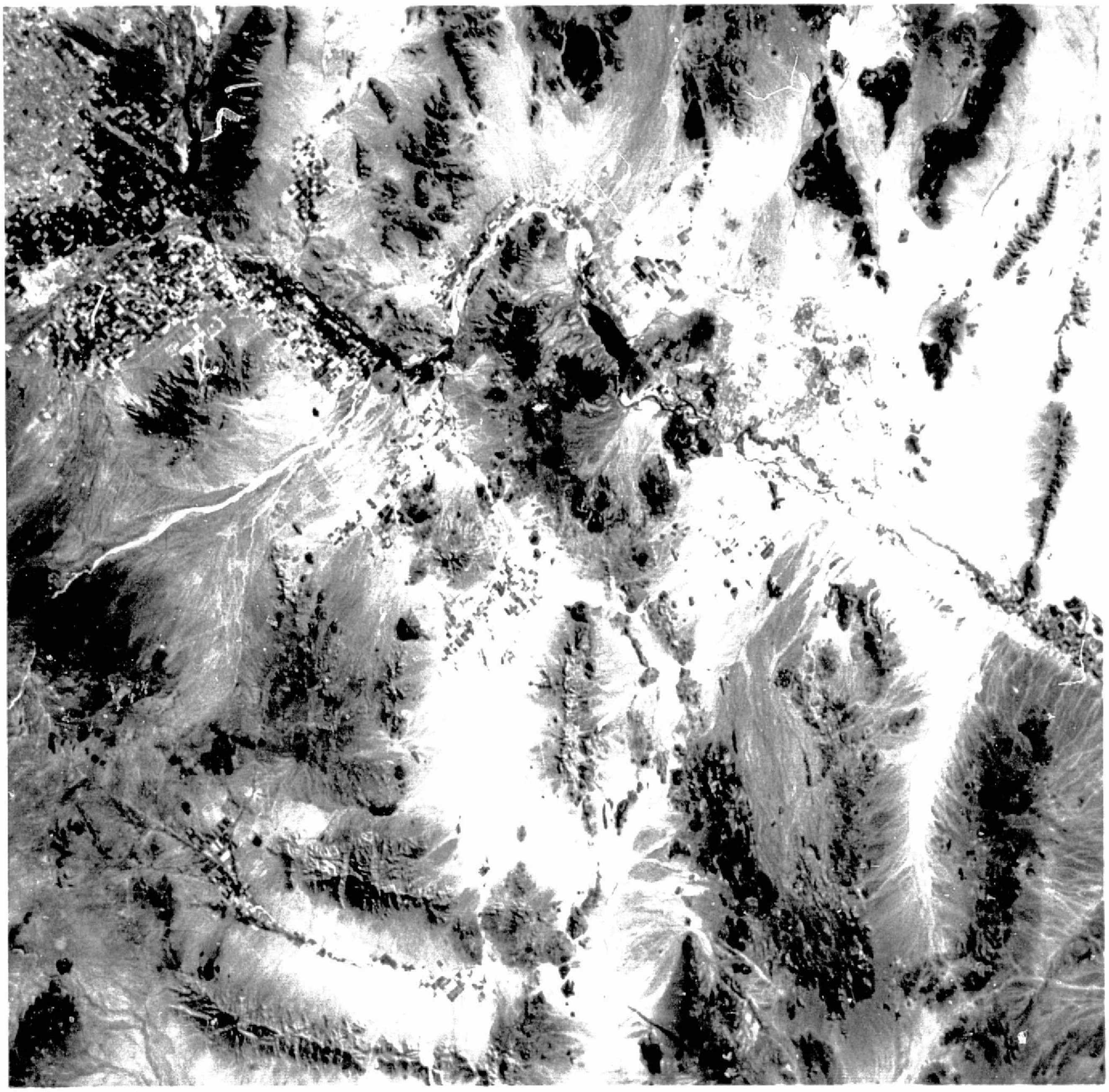
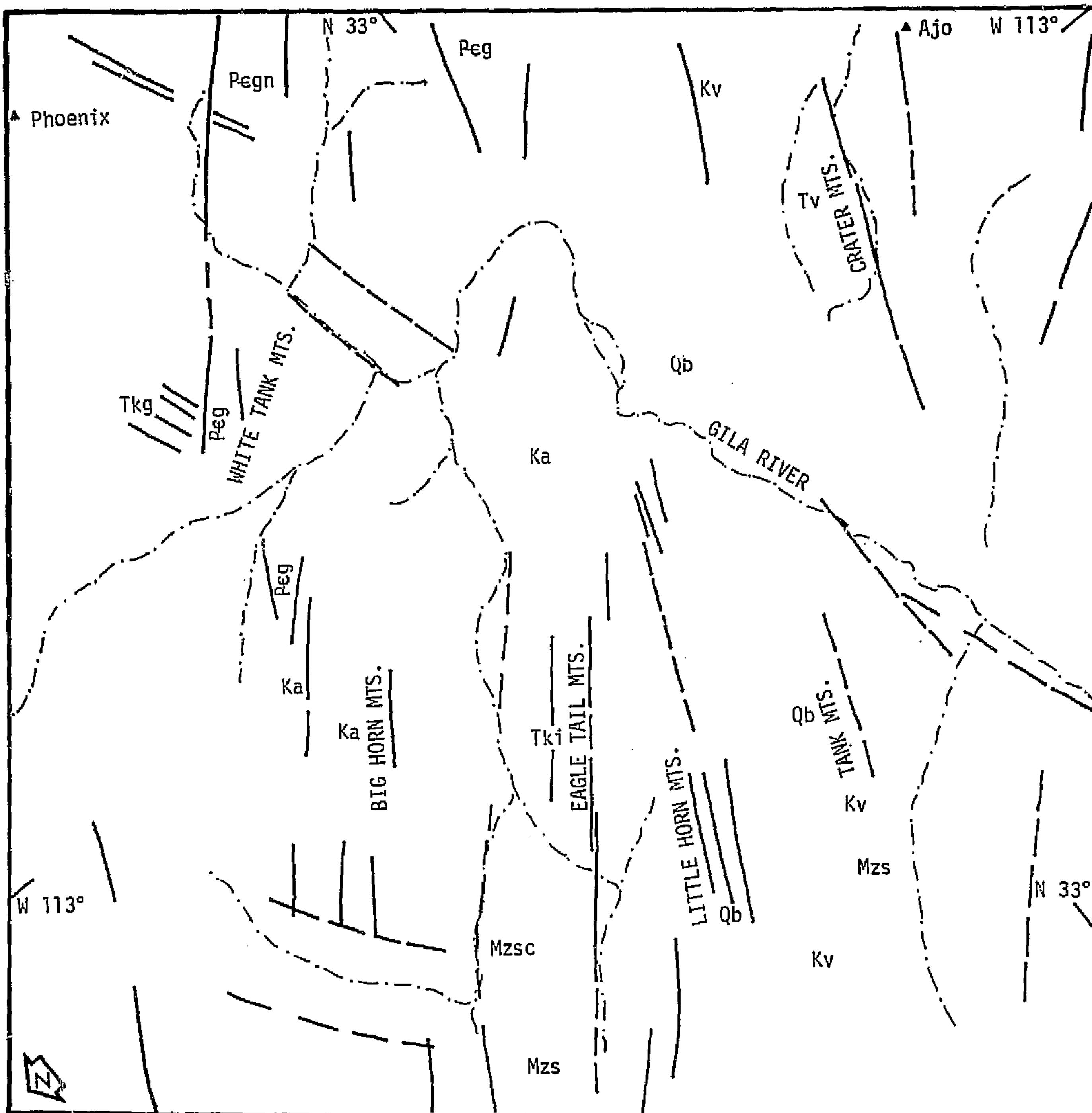


FIGURE 12 EREP SCENE SL4-76-230, SOUTHWESTERN ARIZONA



Legend

0 50 100 km.

▲	Town
—·—·—	Drainage
——— — —	Fault or Linear seen in EREP Imagery
Qb	Quaternary basalts
Tv	Tertiary volcanics
TKi	Tertiary - Cretaceous intrusives
TKg	Tertiary - Cretaceous granites
Ka	Cretaceous andesites
Kv	Cretaceous volcanics
Mzsc	Mesozoic schist
Mzs	Mesozoic sedimentary rocks
Peg	Precambrian granites
Pegn	Precambrian gneiss

FIGURE 13 TRANSVERSE STRUCTURES INFERRED FROM SCENE SL4-76-230

The emplacement of Laramide granitic intrusives such as in Silver Bell and Eagle Tail Mountains seem to be controlled by transverse structures indicating Laramide or earlier age for the initial development of the Texas Tectonic Zone. Recurrence of activity in the Quaternary is suggested, however, by pronounced lineations in the Quaternary volcanic basalts of Little Horn Mountains (Figures 12 and 13). On the other hand, no lineations were observed in the Quaternary basaltic field of Sierra de Pinacate.

<u>Tectonic Model</u>

The distribution of linears, faults or deformation zones, and the time-stratigraphic or rock units affected are significant in understanding the deformation history of the western Cordillera and the tectonic processes involved.

Figure 14 is a sketch of a tectonic model relating the Texas and Parras Shears to three Cordilleran orogenic belts: The Laramide Rocky Mountain folds and thrusts, the Paleozoic Millard mio-geosynclinal belt, and the Mesozoic Nevadan intrusive belt. The model represents some time period predating the Basin and Range fragmentation in the late Cenozoic. Baja California has been reconstructed in a position predating the opening of the Gulf of California.

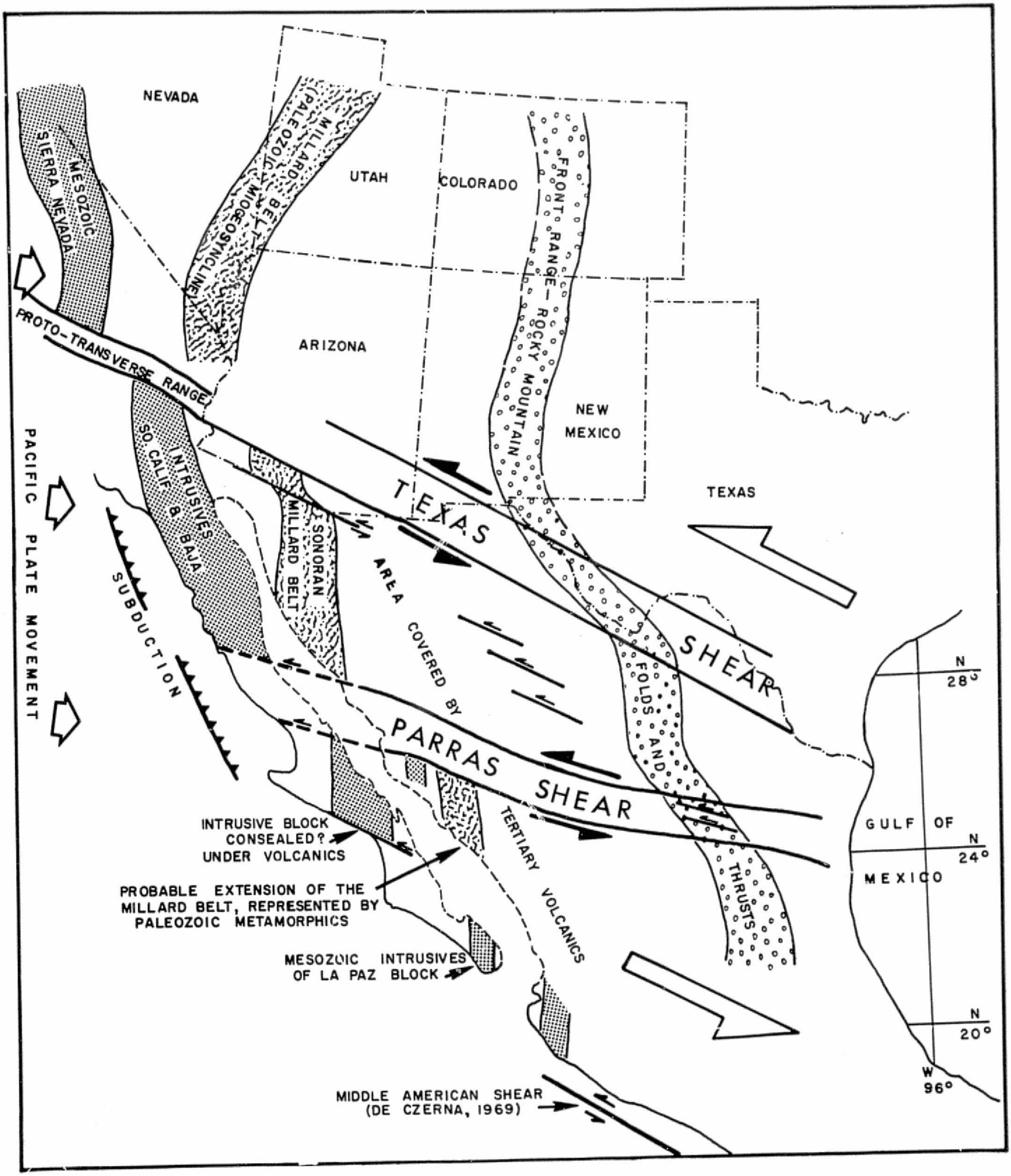


FIGURE 14 TECTONIC MODEL OF PARRAS AND TEXAS SHEARS

Schmitt (1966) interpreted the Texas Zone as a major left-lateral shear and pointed out its apparent offset of the Front Range of the Rocky Mountain belt.

This notion bears profound implications on a long-standing stratigraphic and tectonic problem in western North America.

During the early part of the Paleozoic, North America developed with an interior relatively stable, little subsiding craton, margined with geosynclinal belts of greater subsidence and considerable sedimentation. On the western side of the continent a belt of miogeosynclinal deposition, the Millard Belt, described by Marshall Kay (1947,1951) extended, during the Cambrian through at least the Devonian from beyond Alberta, Canada into eastern California. A thick sedimentary section characteristic of this belt is now exposed in western Utah and in the mountain ranges of eastern and southern Nevada.

The remarkable continuity of the Millard Belt seems to abruptly terminate in southeastern California, a short distance south of the Nevada-California state line. The southern continuation of the belt remained a geological problem until recent studies revealed the existence of marine Paleozoic rocks farther southeast adjacent to the Gulf of California in Sonora, Mexico. The stratigraphy of the Sonoran Paleozoic rocks were found to bear remarkable similarities to those of the Millard Belt of the Great Basin in southern Nevada (King, 1969).

On this evidence, it seems reasonable to assume that the Millard Belt has extended into Sonora during the early Paleozoic. The present disposition of the belt indicates a left-lateral displacement of some 500 kilometers across the projection of the Texas Shear in southern Arizona and California. This notion brings to a focus the importance of delineating the Texas Shear and in particular its projection in the Mojave Desert. This problem will be discussed later in the text. The transverse linears mapped from Skylab and LANDSAT-1 photographs (Figure 4) have a profound significance to this interpretation. Within the Texas Shear the Phoenix - Nueva Rosita fault zone stands out as the most continous strand. The apparent left-lateral offset of the Sierra Nevada intrusive complex relative to the southern California-Baja batholith requires the extension of the Texas Shear along a proto-transverse range shear in southern California.

The present trace of the San Andreas fault with its large right-lateral displacement would seem to pose a most difficult paradox if one assumes that the San Andreas fault has been active since the Mesozoic as suggested by Hill and Dibblee (1953). More recent work by Yeats (1968) and Suppe (1970) suggests that the San Andreas fault has had a more complex history, and questions regarding displacements of ancestral segments have been raised. The conventional notion that all segments of the San Andreas

fault must have had identical movement history has indeed been challenged in recent years.

One solution to this problem requires that the left-lateral offset along the Texas Shear has generally predated the right-lateral movement of the San Andreas system. This would be consistent with proposed models for the Coast Ranges where shearing deformation of the continental margin is presumed to have been a result of unequal stresses of an advancing Pacific plate (Atwater, 1970) colliding and underthrusting the American plate (Abdel-Gawad and Tubbesing, 1974,1975). The compressive style directed eastward towards the continental margin was likely associated with the development of the Franciscan trench in the Mesozoic. The San Andreas fault in its present form most likely could not have existed at that time.

If we consider that the Texas and Parras Shears have developed by the same tectonic process, the latter presents a consistent picture. The Parras Shear does not affect the sedimentary strata bordering the Gulf of Mexico. On the west, Cenozoic volcanic rocks of the Sierra Madre Occidental show little or no transverse deformation which indicates that tectonic activity along the Parras Shear has predated the opening of the Gulf of California.

A third zone of left-lateral shear, Middle American Shear, (Figure 14) similar in trend has been recognized along the

Pacific Coast of Southern Mexico and Middle America (De Czerna, 1969). The broad tectonic pattern seems to indicate that Texas, Parras, and Middle America Shears are elements of a broad deformation between the North American and South American plates.

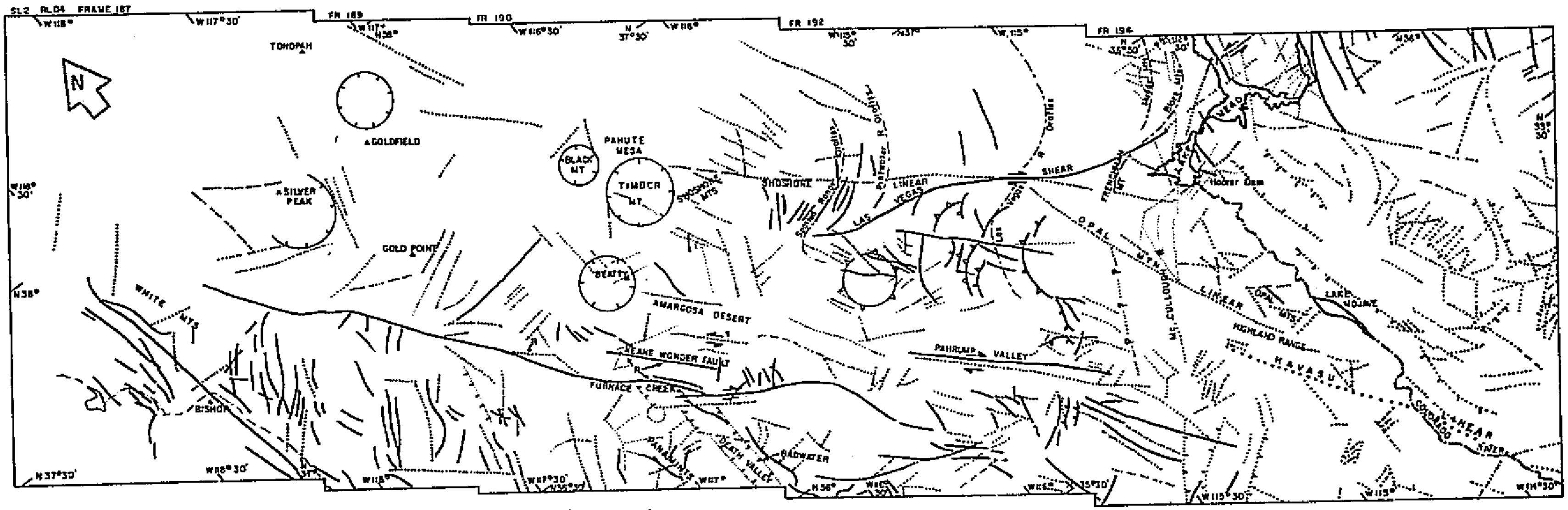
SOUTHERN NEVADA-TECTONIC INTERSECTION

Southern Nevada and adjacent areas of California and Arizona lie at the intersection of the northeast trending Wasatch line with the northwest trending Walker Lane shear belt. The tectonic framework is further complicated by three structural elements which seem to converge in southern Nevada: The Garlock fault which strikes east-northeast; The north trending Black and the Cerbat Mountains of Arizona, and the northeast trending New York and Providence Mountains of California. The southern Nevada intersection is characterized by a great variety of structures, chaotic in places, where block jostling is evidenced by the coexistence of major thrusts, wrench faults with conflicting movements, and Basin Range fragmentation. In this study, we examined the fault pattern at this intersection, utilizing EREP photographs together with geological maps and published literature. Figure 15 is a map assembled from photo-overlays showing known structures and those inferred from EREP photographs. A discussion of important structures follows:

Las Vegas Shear and Shoshone Linear

The Las Vegas Shear has been discussed by Albers 1964; Burchfiel 1965; Longwell 1960, 1965; Hamilton and Myers 1966; Stewart, *et al* 1968; and others.

A right-lateral displacement of at least 40 km on the Las Vegas Shear was suggested by Ross (1964). The fault strikes



Legend

▲ Town
—— Known fault
·········· Skylab suspected fault or linear
R Fault that shows evidence of recent movement
—·—·— Drainage
0 50 100 km

SL2 FRAMES: 194, 192, 190, 189, 187

FIGURE 15 FAULT AND LINEAR MAP OF SOUTHERN NEVADA INTERSECTION

northwestward across older structures which strike north and northeast. The fault trace is mostly concealed beneath the alluvial fill of broad valleys and its southeastern and northwestern extensions are uncertain. The northwestern part of Las Vegas Shear trends west-northwest and presumably passes south of Spotted Range. EREP imagery does not provide additional evidence on any westward extension. The fault presumably dies out or more likely terminates as it joins a thrust fault. Opinions vary as to the southeast extension of the fault. For example, Hamilton and Myers (1966) suggest that the fault passes south rather than north of Frenchman Mountains.

Interpretation of EREP photographs suggests that a branch of the Las Vegas Shear or an extension of the Shoshone linear passes south of Frenchman Mountains, (Figure 15).

The Shoshone linear is an interesting feature observed in EREP photographs. The linear projects northwestward towards the Timber Mountain Caldera crossing the Pintwater and Spotted Ranges without any significant lateral displacement. South of Yucca Lake distinct lineations parallel to the Shoshone linear are observed. The structure appears to extend beyond the Timber Mountain Caldera towards the vicinity of Goldfield, Nevada. It may represent a very young or incipient fault zone perhaps related to the development of the Timber and Black Mountain Calderas. Earthquake epicenter plots indicate moderate seismic

activity in the area. The seismic record, however, may partly be caused by nuclear and gunnery testing. The Shoshone linear projects southeast towards the Hoover Dam area, where field evidence of lateral shear is indicated by horizontal slickenside marks in the Tertiary volcanics of the Black Canyon area.

Opal Mt. and Havasu Linears

Two major *en echelon* linears are observed in EREP photographs: Opal Mountain linear extends from a point near the intersection of the Las Vegas Shear with Las Vegas Range, southeastward crossing McCollough Range and passing between Opal Mountains and Highland Range, Nevada.

Havasu linear is another structure of similar strike which appears to control the bend of the Colorado River at Lake Havasu, Figure 15.

Sinistral Strike-Slip

Skylab, LANDSAT-1, and Apollo 9 photographs of Lake Mead area show prominent east-northeast faults across the south Virgin Mountains which appear to continue across Lake Mead into Muddy and Black Mountains (Fig. 15). Portions of these faults are shown on the Geologic Map of Clark County, Nevada (Longwell, Pampeyan and Bowyer, 1965). These faults appear to control the course of the Colorado River in Lake Mead area. Lineations of similar trend are observed south of Lake Mead across the White Hills (north of Cerbat Mountains) and Black Mountains, Arizona

(Fig. 6). In the South Virgin Mountains the fault which runs along Catclaw Wash juxtaposes the Paleozoic and Mesozoic strata of Lime and Tramp Ridges against the Precambrian metamorphics to the south. The Paleozoic strata of Azure Ridge appear to be offset some 20 km. left-laterally from the Paleozoic sequence north of the fault (Lime Ridge). East-northeast lineations are observed in EREP photographs across the Tertiary volcanics in the vicinity of Hoover Dam and further east across the White Hills (Figures 16 and 17).

The relationship of these faults to the great fault system of the Wasatch Line which cut the western part of the Grand Canyon remains uncertain. The Hurricane fault, a member of the Wasatch system strikes N 15° E and shows evidence of left-lateral movement, suggesting regional shear along the Wasatch line. The Lake Mead faults, on the other hand, are significantly different in strike (N 65° E). A possible explanation for the anomalous strike may be the clockwise rotation of the Lake Mead area.

Field Observations

The stresses of regional shear in the southern Nevada intersection are reflected in the volcanic rocks exposed in Lake Mead area. During a field trip to the Black Canyon area, we noted that the Golden Door Volcanics in the vicinity of Hoover Dam are cut by northwest and east - northeast faults. Along fault and joint planes of the two sets, horizontal slickenside

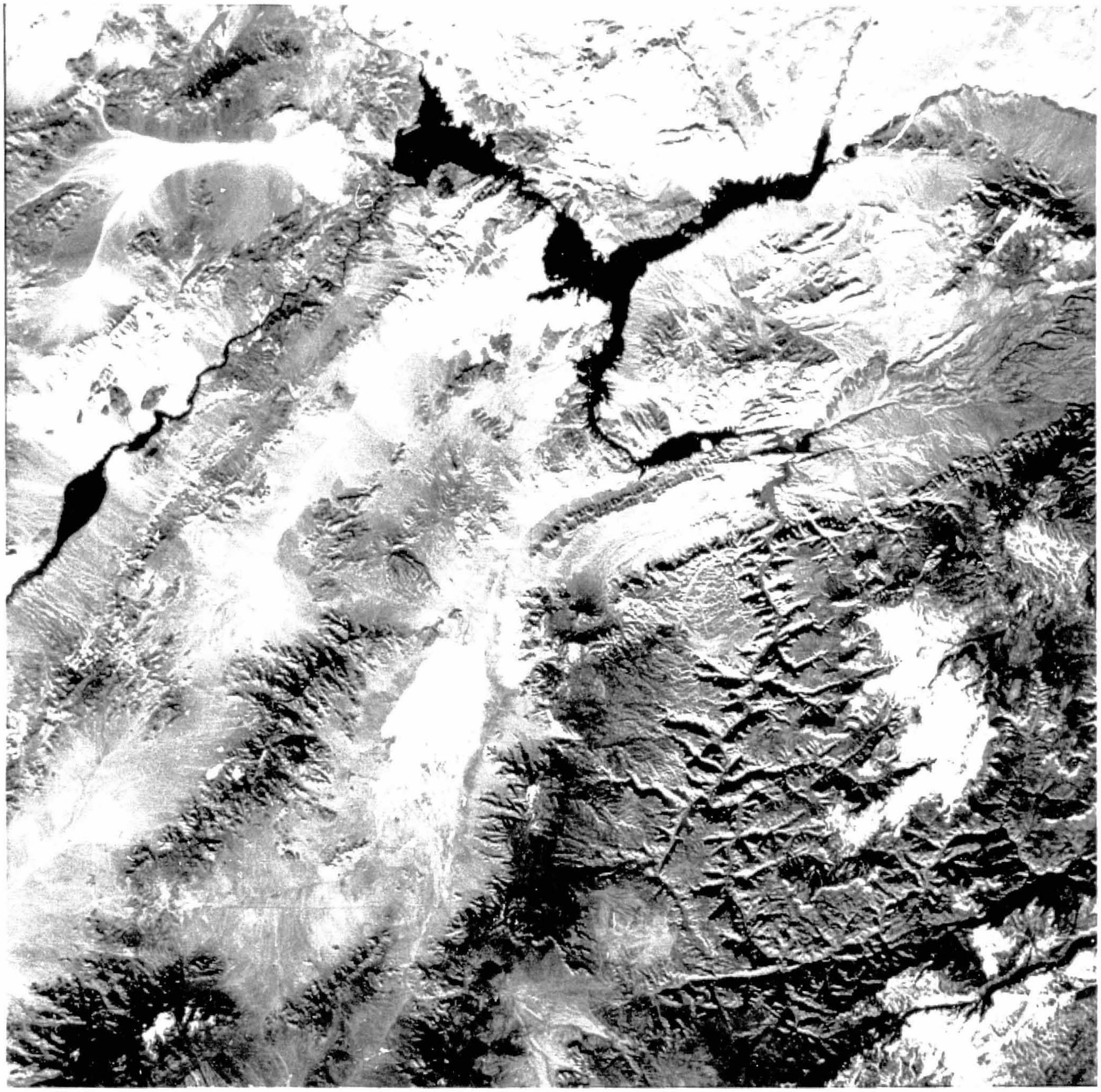


FIGURE 16 EREP SCENE SL4-4B-030, LAKE MEAD AREA

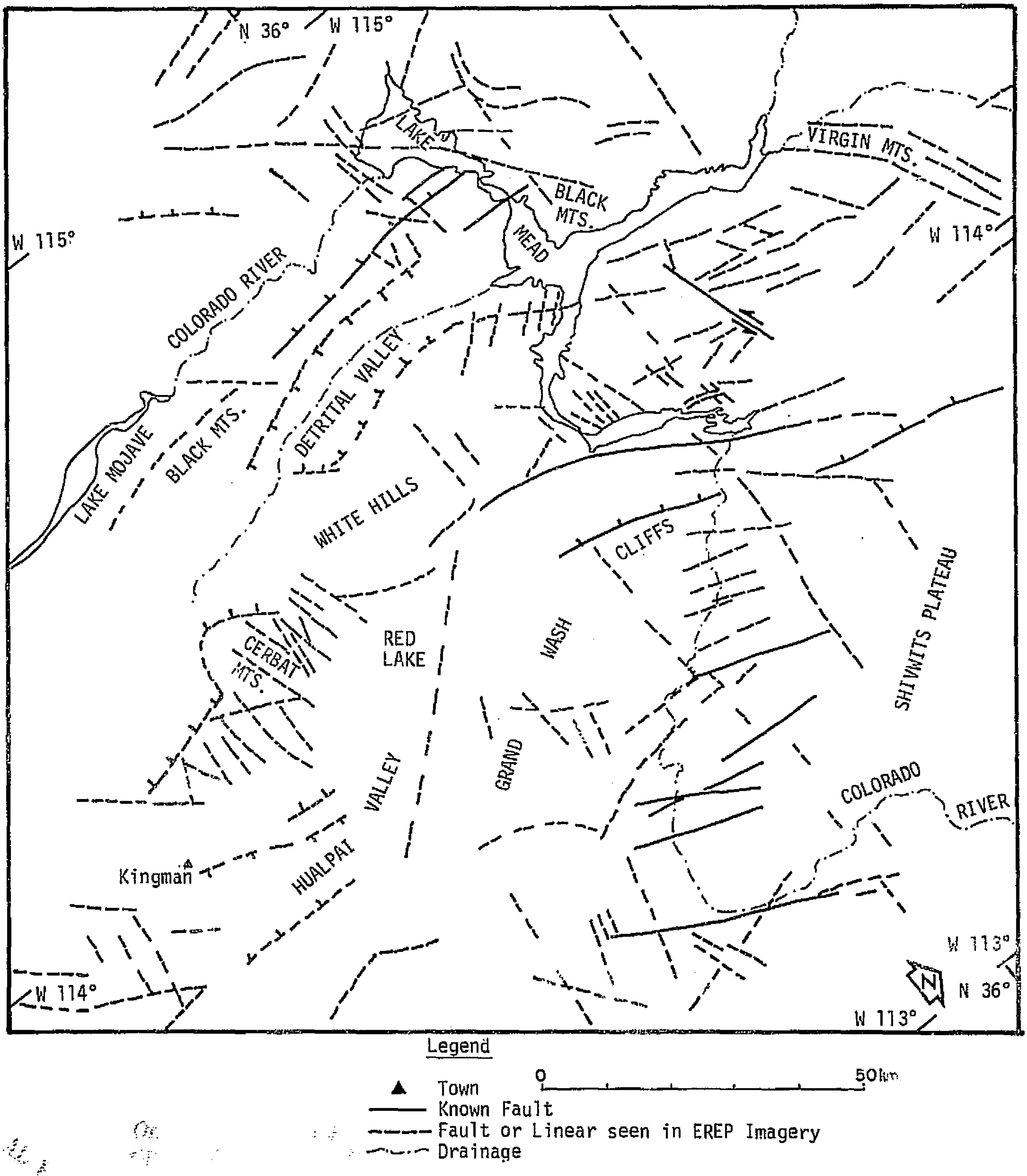
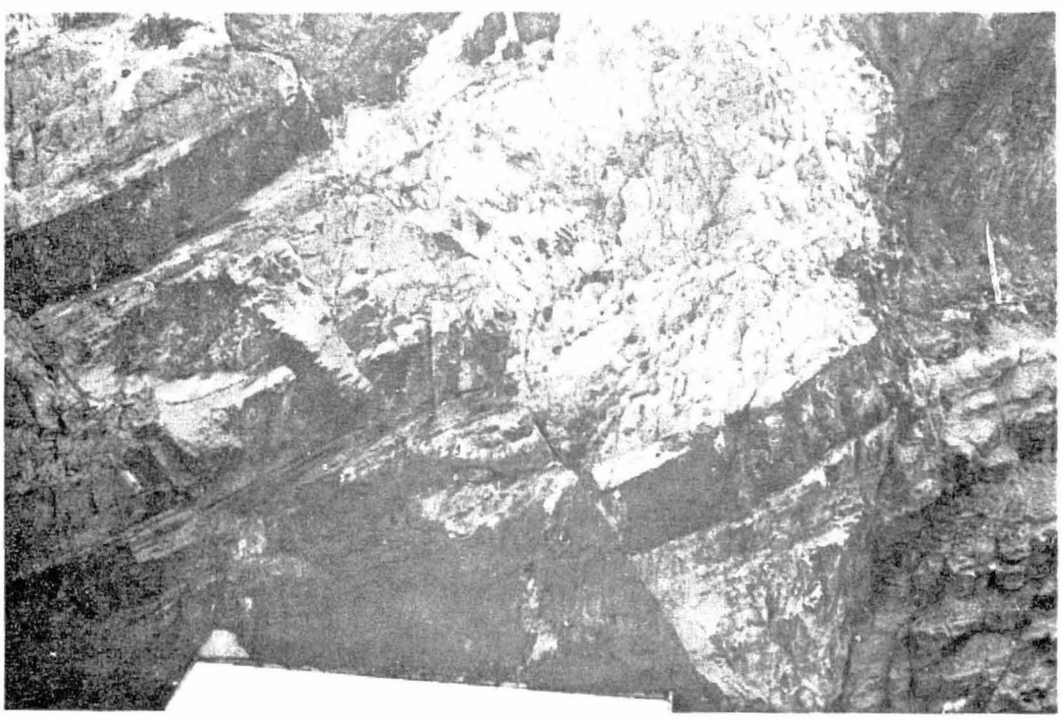


FIGURE 17 STRUCTURES INFERRED FROM EREP SCENE SL4-4B-030

marks are very common. They can be observed along highway 93 from Boulder City. Figure 18 shows examples in the volcanics which cutcrop on the Nevada side of Hoover Dam. An observer standing at the Nevada Side of the dam sees across the Black Canyon in Arizona inclined volcanic dikes displaced by high angle faults. The apparent offsets seem to a casual observer as normal dip-slip movement (Fig. 18). Taking into account the horizontal slickenside marks these offsets could be caused by lateral movements.

In Fig. 19 a right-lateral fault across a south dipping dike would cause an apparent dip-slip offset on the eroded canyon wall similar to that resulting from a left-lateral fault displacing a north dipping dike. In both cases the apparent offsets could mistakenly be attributed to dip-slip movement. The faulted dike appears to dip towards the southeast but we could not get exact measurements during our brief visit to the area. However, observations on the width of grooves associated with slickenside marks and direction of tapering suggest right-lateral movement on the northwest trending faults. Groove marks along the east-northeast fault planes suggest left-lateral motion. The pervasive occurrence of horizontal slickenside marks on two sets of fault planes could result from regional north-south compression and east-west extension affecting the Lake Mead area, with lateral movements on two conjugate sets of shear fractures.

a) HORIZONTAL SLICKENSIDES ON TWO SETS OF FAULT PLANES, HOOVER DAM AREA



b) FAULTED DIKES ON ARIZONA SIDE OF HOOVER DAM

FIGURE 18

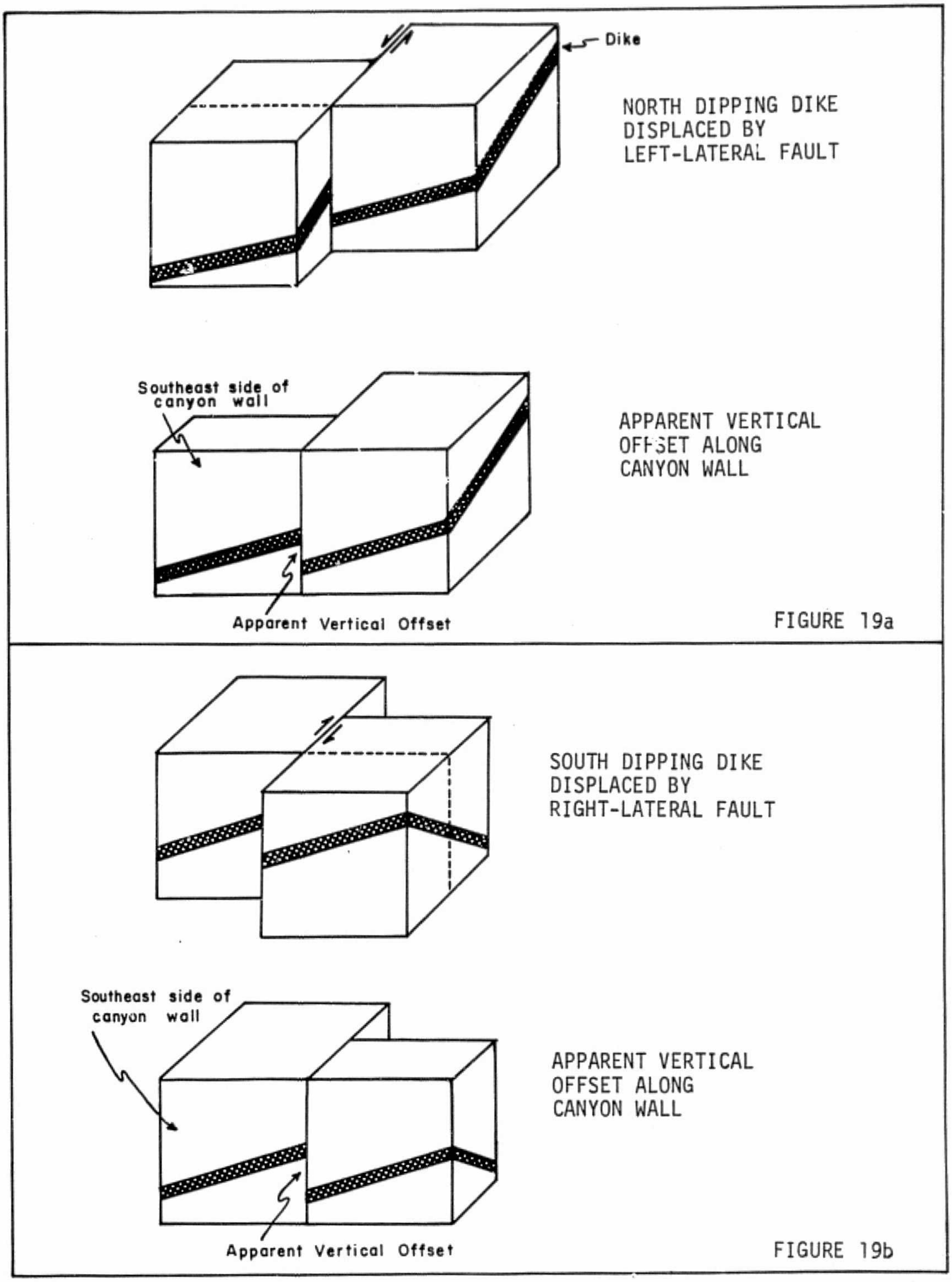


FIGURE 19 APPARENT DIP-SLIP OFFSETS CAUSED BY STRIKE-SLIP MOTION

On the other hand if we allow for the possibility of clockwise rotation in the Lake Mead area the two sets of faults may very likely be related to regional shear on the Walker Lane and Wasatch tectonic belts.

Furnace Creek Fault and Death Valley

EREP S-190A photographs (SL2, RL04, Frames 189, 190 and 192) show that the Furnace Creek fault is one of a system of en echelon wrench faults which cut older structures in southern Nevada. Contrary to the older edition of the Death Valley Geological Map (Jennings, 1958) the Furnace Creek fault does not appear to extend along the Amargosa River Valley west of Resting Spring Range. The fault appears to abruptly end against the Resting Spring Range. The Stewart Valley - Mesquite Valley fault zone extends en echelon to the Furnace Creek fault. Hamilton and Myers (1966) analyzed stratigraphic relationships across Death Valley and the Furnace Creek fault and found evidence of 80-100 km cumulative right-lateral displacement on both structures. Analysis of EREP and LANDSAT-1 photographs did not provide any new data of relevance to the amount of displacement. However, one gets the impression that the Death Valley is a rift or pull-apart structure (Burchfiel and Stewart, 1966) typical of many Basin and Range valleys. The Furnace Creek fault is one of many en echelon wrench or transform faults which cut oblique to the rift valleys, a relationship diagramatically illustrated in

Figure 20. EREP photographs show a possible fault along the west side of the Amargosa Desert. The Precambrian and overlying Paleozoic section of the eastern side of the Funeral Range appear to be offset left-laterally about 3 km along the fault which runs parallel to the Furnace Creek and Keane Wonder faults (Fig. 15). A left-lateral offset on a northwest trending fault within the general domain of the Walker Lane shear system is indeed anomalous and may be significant. The coexistence of right- and left-lateral wrench or transform faults transverse to Basin and Range rifts would be expected where rifts are differentially pulled apart (Abdel-Gawad and Tubbesing, 1974, 1975).

Garlock Fault and Death Valley Intersection

The Garlock fault is a transverse wrench fault separating the Sierra Nevada and the Mojave Desert block. The fault extends from the southern end of the Death Valley and is intersected at the western end by the San Andreas fault. Smith (1962) reported that a swarm of dikes are left-laterally displaced some 70 km across the fault. Offset drainage and breaks in the alluvium indicate Quaternary movement. The total offset amounts to approximately one third of the total length of the fault which poses a geometrical problem in the movement of adjacent blocks. Five alternatives have to be considered.

1) The reported displacement is excessive and the correlation of the dike swarms across the fault may not be valid.

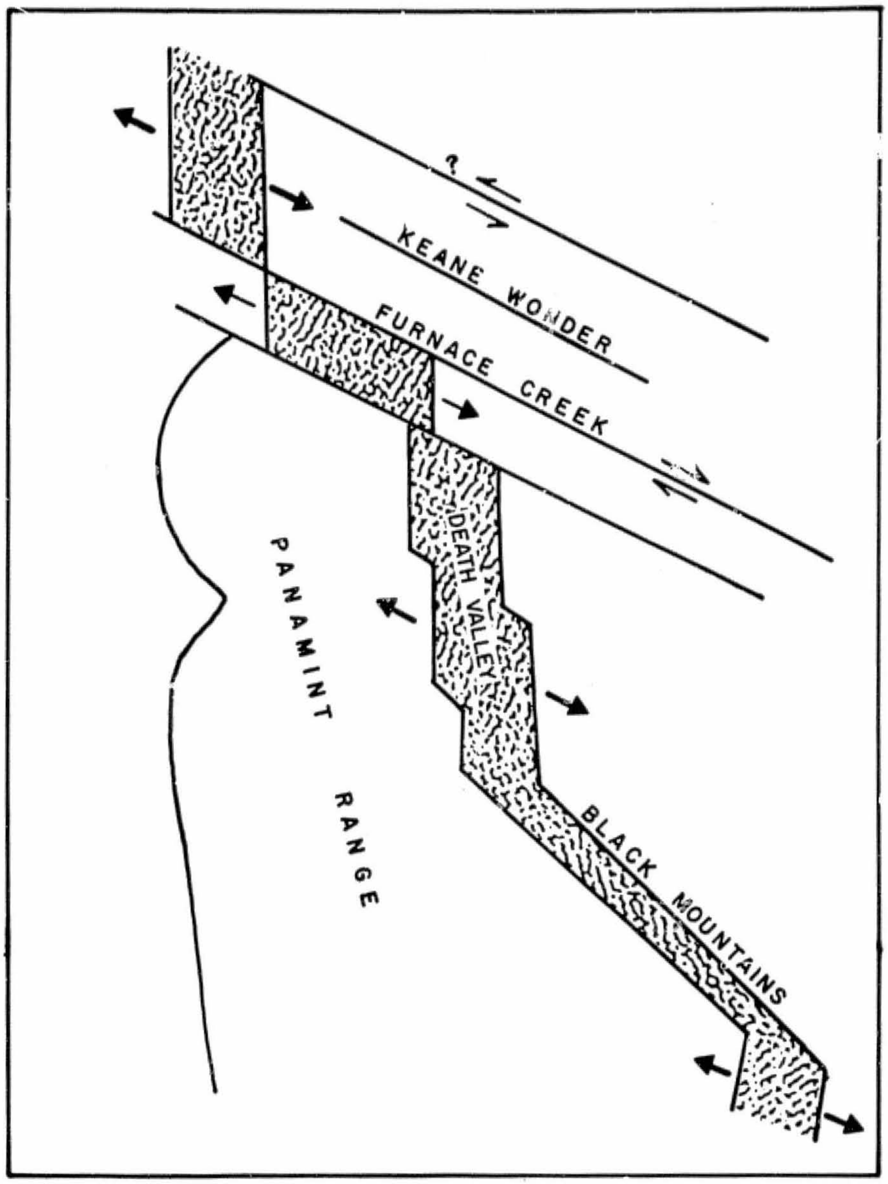


FIGURE 20 RIFT AND SHEAR MODEL FOR DEATH VALLEY, CALIFORNIA

2) The fault is a continental transform fault and the apparent offset was caused by tensional pull-apart rifting across the Death Valley, Panamint Valley and Owens Valley.

3) Thrusting on the eastern side of the Mojave Desert block and/or the western side of the Sierra Nevada under the Great Valley.

4) That either or both ends of the fault have been truncated by younger faults and displaced. In that case, the western end would be offset northwestward by the San Andreas fault and the eastern by a fault extending southward from the Death Valley.

5) A combination of the four hypotheses.

We have considered these alternatives during the analysis of EREP photographs. A summary of observations and conclusions follows:

1) We found no direct evidence which either contradicts or supports the reported 70 km left-lateral displacement on the Garlock fault. Although we are inclined to accept the validity of the reported offset for indirect geological reasons. The suite of basic intrusives, Mesozoic volcanic and metamorphic rocks, which occur in the central part of the Mojave block, may conceivably be the southward extension of a similar rock suite occupying the central and western

side of the Sierra Nevada. The geometric position is consistent with left-lateral offset on the Garlock fault.

2) The tensional rift model for the Death Valley proposed by Burchfiel and Stewart (1966), Hamilton and Myers (1966) and others is consistent, at least in part with the transform fault model for the Garlock fault.

3) We found no evidence from EREP photographs to indicate the existence of any major thrust on the eastern side of the Mojave Desert block. EREP photographs did not provide direct evidence for underthrusting of the southwestern side of the Sierra Nevada block under the San Joaquin Valley. The bend of the San Andreas fault near its junction with the Garlock fault and the left-lateral movement on faults of the western Transverse Ranges may, however, be partly caused by westward movement of the Sierra Nevada.

4) Interpretation of EREP photographs of the Death Valley Garlock fault intersection suggests that both structures are mutually displacive. Recent faulting belonging to both structures is inferred in the Avawatz Mountains area (Figures 21 and 22). A detailed study of EREP photographs indicates that an eastward extension of the Garlock fault beyond its known trace is very unlikely. The photographs show, however, a major fault zone extending from the southern end of the Death Valley truncating the Garlock

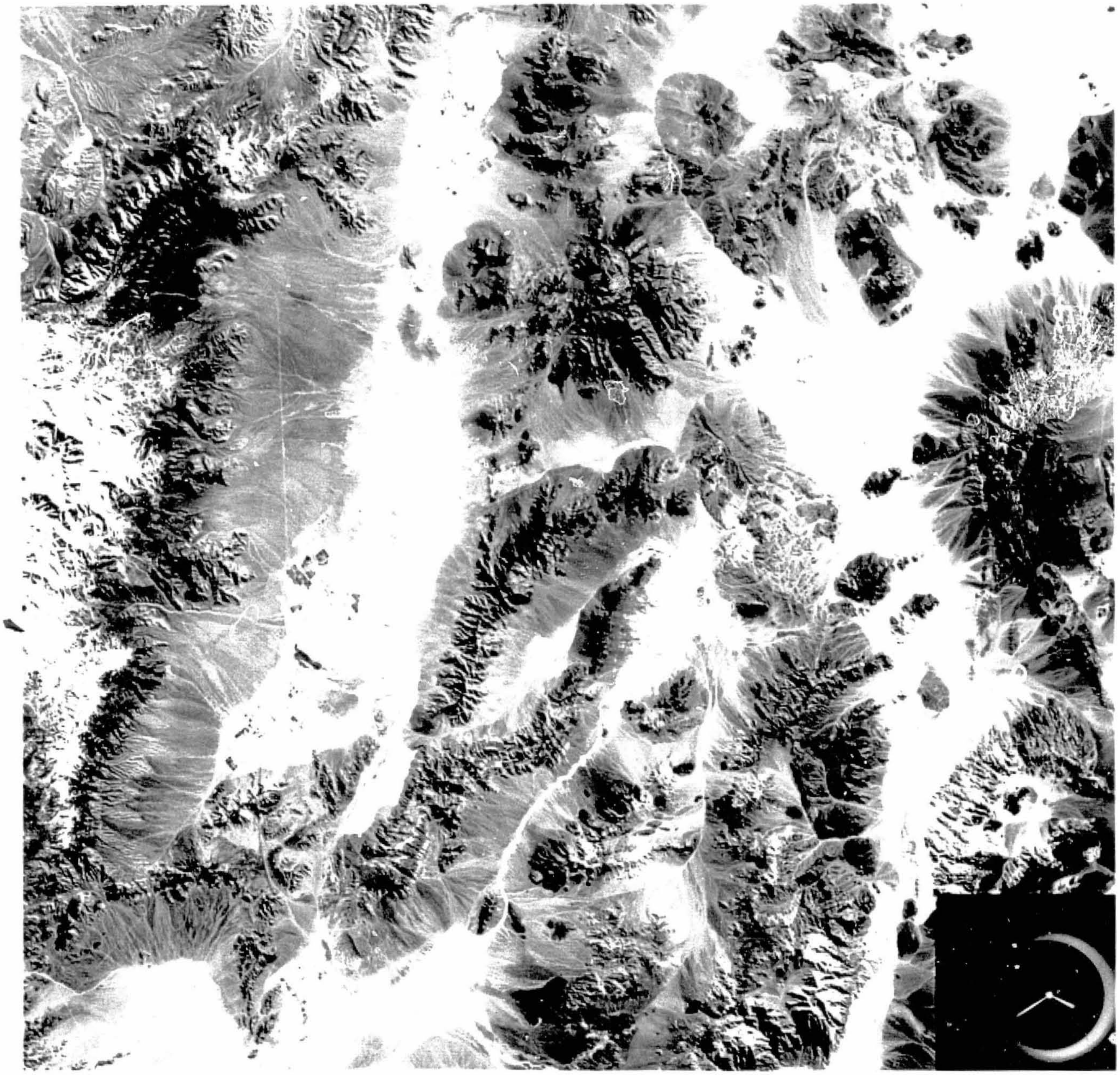
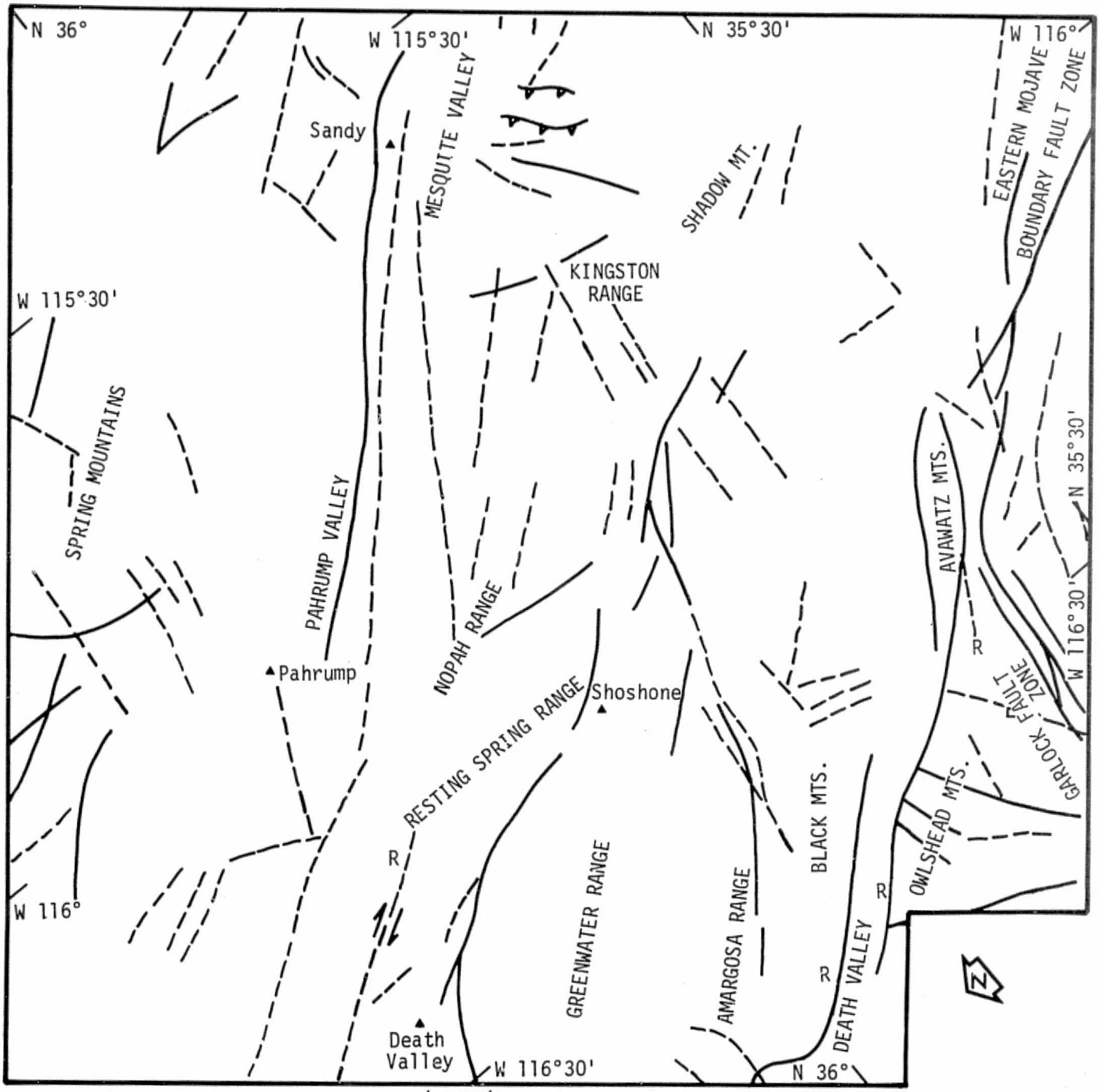


FIGURE 21 EREP SCENE SL4-94-016, SHOWING DEATH VALLEY, GARLOCK FAULT INTERSECTION



Legend

0 10 20 km.

▲ Town
——— Known Fault
– – – Fault or Linear seen in EREP Imagery
R Fault Showing Evidence of Recent Movement

FIGURE 22 STRUCTURES AT DEATH VALLEY, GARLOCK FAULT INTERSECTION, INFERRED FROM EREP SCENE SL4-94-016

fault on the eastern side of Avawatz Mountains. This fault may very well mark the eastern structural boundary of the Mojave block and its significance will be discussed further in the text.

Mojave Block and Texas Belt

The great belt of transverse linears, which extends from the vicinity of the Gulf of Mexico northwestward through southwestern Arizona, projects towards the Mojave Desert in California. East of the Colorado River between Mojave City and Yuma, lineations related to the Texas Zone are readily identified. West of the Colorado River, however, the extension of the Texas Belt through the Mojave Desert is uncertain. The structure of the Mojave Desert is complicated by considerable fragmentation and by younger, northwest trending right - lateral faults which parallel the San Andreas system. Moreover, older structures tend to be concealed under younger volcanic flows, extensive alluvium and Pleistocene lake beds and related blankets of windblown sand. Figure 23 shows the fault pattern in the Mojave Desert partly inferred from EREP photographs.

There are two important and related features in the fault pattern which deserve special attention: a) the Eastern Mojave Boundary Fault and b) the abnormal strike of transverse faults. As stated previously, we found no evidence for an eastward extension of the Garlock fault. Rather, at the intersection with

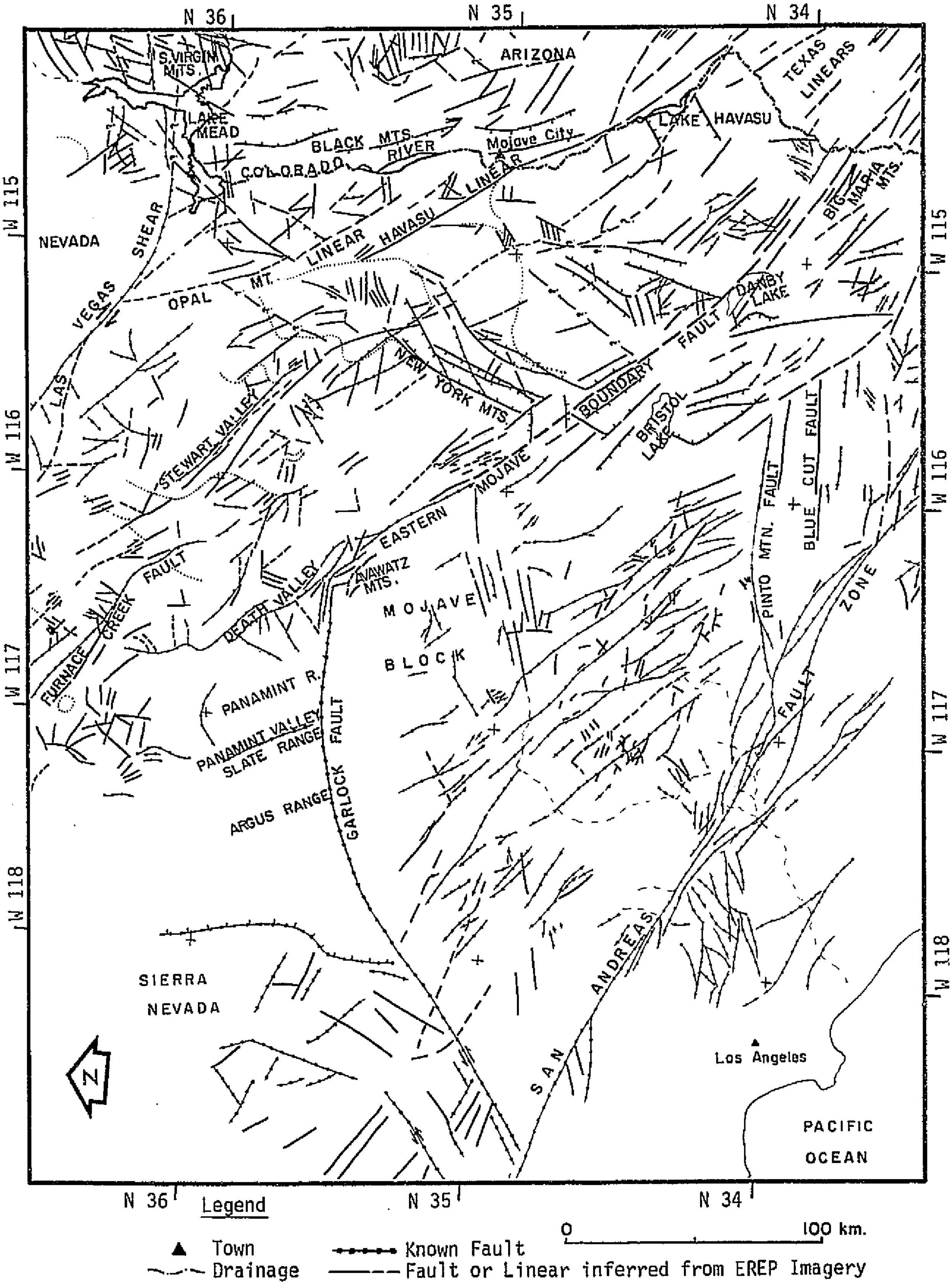


FIGURE 23 FAULT PATTERN IN THE MOJAVE DESERT BLOCK

the southern end of the Death Valley, the Garlock fault is cut-off by a major northwest trending fault, which, for practical reasons, may be considered a continuation of the Death Valley fault zone (Hamilton and Myers, 1966; Johns and Wright, 1960; Grose, 1959). With due credit to the eminent geologists who have described this fault, we shall refer to it here as the Eastern Mojave Boundary Fault in order to avoid any confusion with the main Death Valley rift. Although the principal sense of movement is right-lateral, the fault differs from the Death Valley rift by the apparent lack of cross strike extension. The main strand of the Eastern Mojave Boundary fault can be followed from the eastern side of Avawatz Mountains southeastward along the western side of Old Dad Mountains (Devil's Playground area), Clipper Valley, under Danby Lake and across the Colorado River Valley north of Big Maria Mountains (Figures 24 and 25). The fault zone affects a broader area on both sides of its main strand.

This break most likely represents the structural boundary between the Mojave block on the west and Basin and Range structures on the east. The fault pattern in the Mojave block between this line and the San Andreas fault is dominated by either right-lateral northwest trending faults or by left-lateral transverse faults trending east and east - northeast. The area lying northeast between this line and the Colorado River is dominated by Basin and Range fault blocks trending northeast and

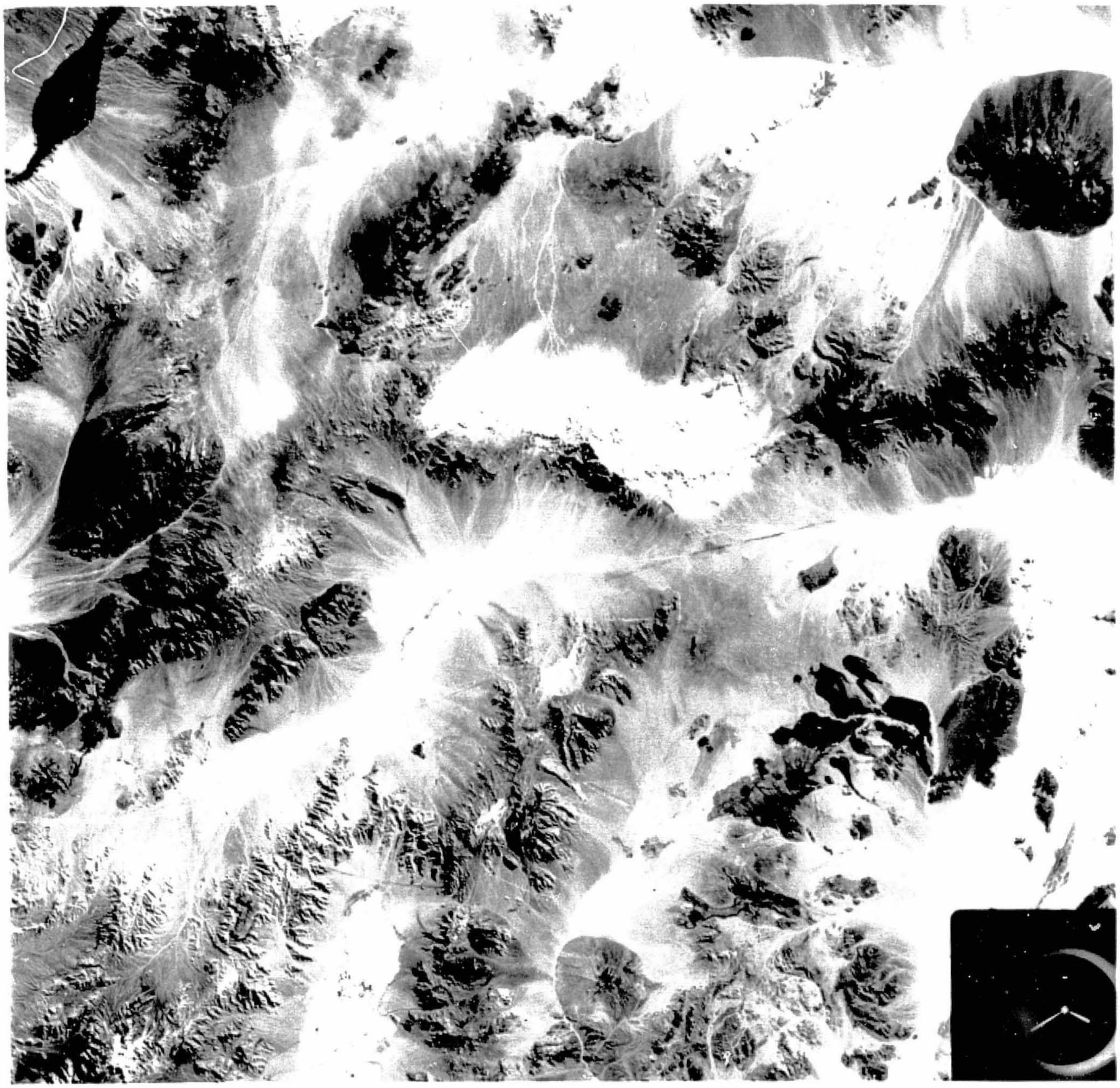
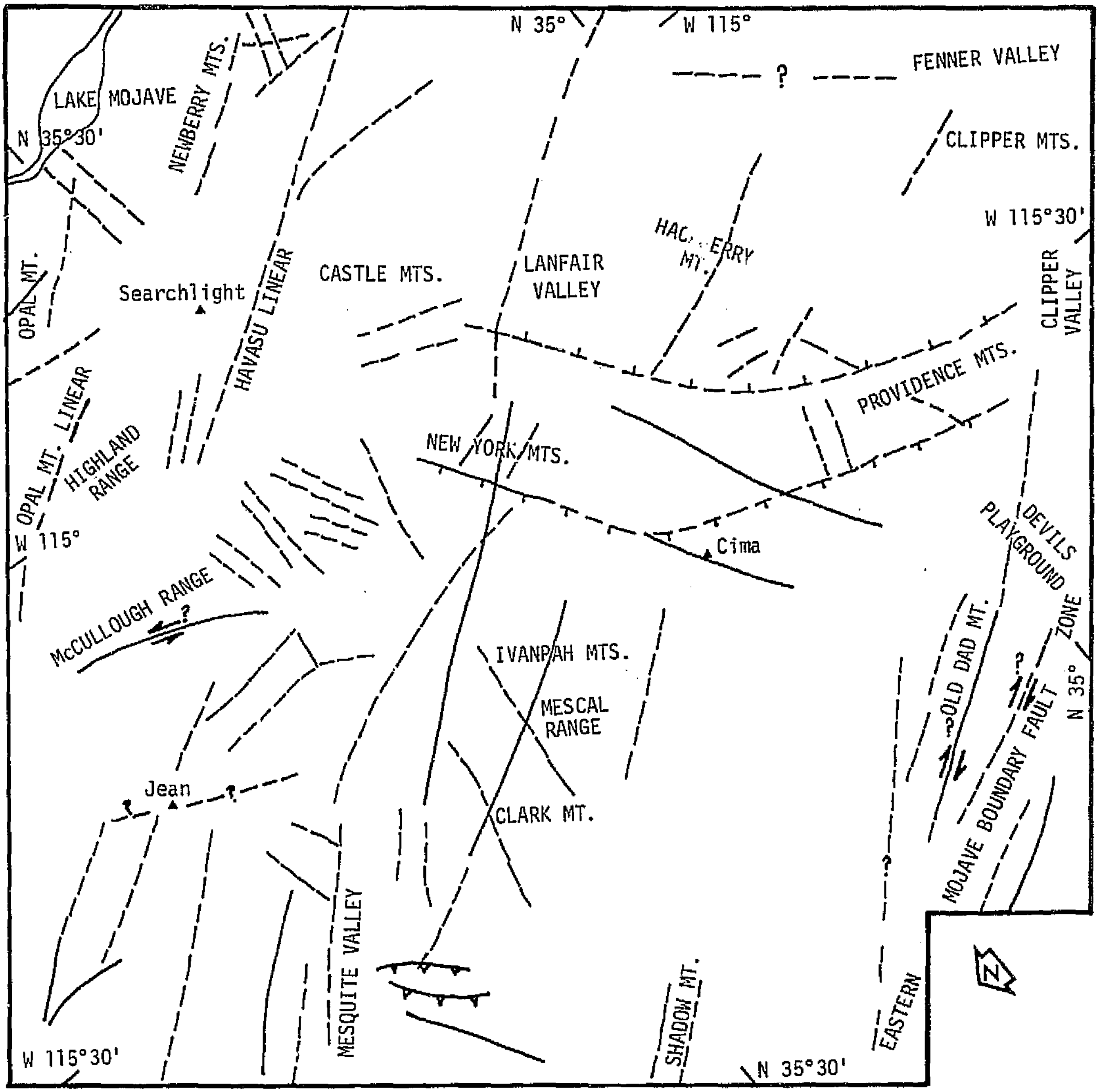


FIGURE 24 EREP SCENE SL4-94-018, EASTERN MOJAVE DESERT



Legend

▲ Town
——— Known Fault
–·–·– Fault or Linear seen in EREP Imagery

FIGURE 25 EASTERN MOJAVE DESERT BOUNDARY FAULT, INFERRED FROM EREP SCENE SL4-94-018

sliced by northwest faults which represent a continuation of the Walker Lane shear belt. Although relatively small in area, the structural position of the Mojave block is important in the tectonic history of the Western Cordillera. The Mojave block lies to the south of the Sierra Nevada and most likely represents a southern collapsed part. It also lies where the Texas Tectonic Zone most likely passes for continuation along the Transverse Ranges. The regional strike of the Texas Zone is approximately N 60°W. Yet the transverse faults in the Mojave block are significantly anomalous to this regional trend. This is particularly true for the Garlock fault which trends east-northeast, and Pinto, Aqueduct, Blue Cut and other faults which dominate the Eastern Transverse Ranges adjacent to the Salton Sea, and also many fault segments observed in EREP photographs throughout the Mojave Desert.

The angular difference between the regional strike of the Texas Zone and the transverse faults in the Mojave block exceeds 25°. If we then assume that the transverse faults in the Mojave block are related to the Texas Zone, their anomalous strike would seem to indicate that the Mojave block has rotated counterclockwise some 25° relative to main block southeast of the Colorado River.

On the basis of strike difference in the dike swarms north and south of the Garlock fault, Smith (1966) suggested that the

Mojave block has rotated 25° clockwise relative to Sierra Nevada block. Michael (1966) and Garfunkel (1974), however, argued for an opposite sense of rotation on the basis of structural alignments. We are inclined to believe that much of the rotation of the Mojave block has taken place as a unit with a general counterclockwise rotation of the Sierra Nevada block and its movement towards the northwest along the Walker Lane Shear.

Reconstruction would bring the transverse faults of the Mojave block more closely in alignment with the regional strike of the Texas Zone, particularly the transverse faults in Lake Havasu area.

TECTONIC IMPLICATIONS

Figures 5A,15 and 23 show the fault pattern in southern Nevada, the Mojave block, and western Arizona assembled both from Skylab (EREP) photographs and geological maps. Generalized maps outlining the principal fault zones are shown in Figures 5A and 23. The principal fault systems are: a) In the area lying between the Colorado River south of Lake Mead and the Mojave block the structural framework is dominated by northwest trending faults and linears representing an extension of the Walker Lane Shear belt. Outstanding examples are the Eastern Mojave Boundary fault, Death Valley, Furnace Creek, Stewart Valley faults, Las Vegas Shear, Opal Mountain and Havasu linears. The predominant movement on this system is right-lateral. This area is also

broken into northeast trending blocks of Basin and Range type. The Lake Mead area lies in the domain of the Walker Lane Shear and Wasatch system. The east - northeast left lateral faults cutting the Virgin Mountains are interpreted as rotated elements of the Wasatch system. East of the Colorado River, between Lake Mojave and Yuma, west - northwest linears of the Texas Zone can be recognized. In the Mojave block the Garlock, Pinto Mountain, Blue Cut faults and fault segments of similar trend are interpreted as elements of the Texas Zone which have been rotated counterclockwise with the Mojave and Sierra Nevada blocks. The Mojave block is also cut by a younger system of northwest faults.

Our interpretation of the fault pattern outlined below is pivoted on three main hypothesis:

1) Schmitt's (1966) interpretation of the Texas Zone as a major belt of left-lateral shear.

2) Hamilton and Meyer's (1966) rotation model for the Sierra Nevada and oblique tensional rifting in the Basin and Range province.

3) The hypothesis adopted in this report that the Mojave block has rotated counterclockwise at least 25° together with the Sierra Nevada.

Figure 26 is a diagrammatic reconstruction of selected crustal blocks in the Western Cordillera at a time preceding the development of the Texas Shear and subsequent Basin and Range

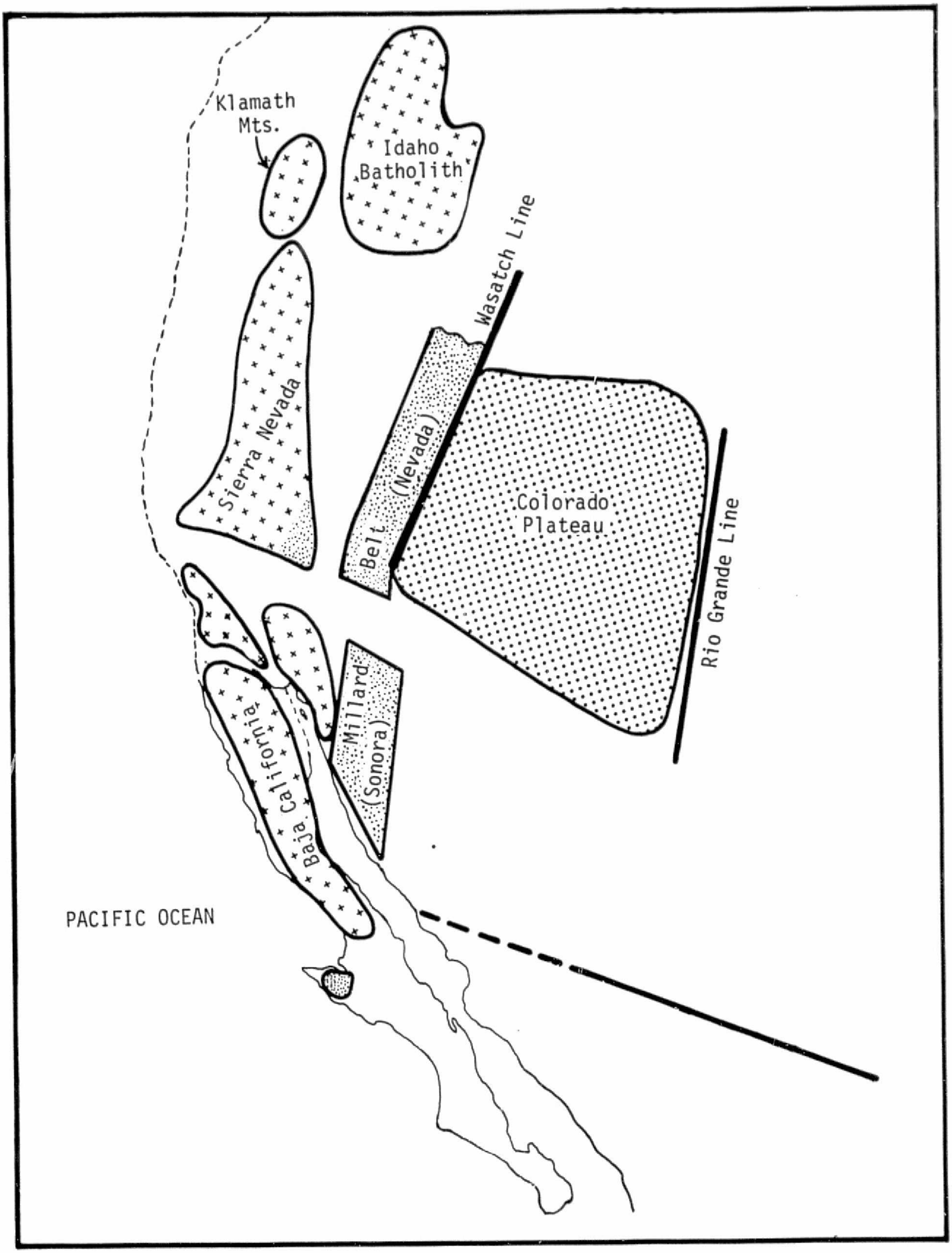


FIGURE 26 RECONSTRUCTION MODEL FOR SELECTED BLOCKS IN WESTERN CORDILLERA

fragmentation. The model was derived from the present tectonic disposition (Figure 27) by the following manipulations:

a) Baja California was moved some 480 km southeastward and closer to the Mexican mainland so that the southern tip of the peninsula fits the bulge of Jalisco. This reconstruction was suggested by Hamilton (1961) and later by Rusnak et al (1964) and others.

b) Removal of large blocks in eastern Oregon, southern Washington, and northern Idaho now covered by extensive Tertiary and Quaternary volcanic rocks. The blocks removed represent mostly the Columbia Plateau, the Snake River volcanic area and the eastern Cascade Mountains. The removal of these blocks implies that the volcanic rocks represent new crustal material, (Hamilton and Myers, 1966).

c) Clockwise rotation of the Sierra Nevada Block together with the Klamath Mountains and the Mojave block through 25° together with 150 km lateral movement towards the southeast. This rotation brings the Sierra Nevada and Klamath blocks more nearly in alignment with the Idaho Batholith.

d) Telescoping of the Basin and Range structures in Nevada and western Utah, accordian style. The notion that the Basin and Range province in Nevada is a rift system which has undergone considerable extension and translaticn is now

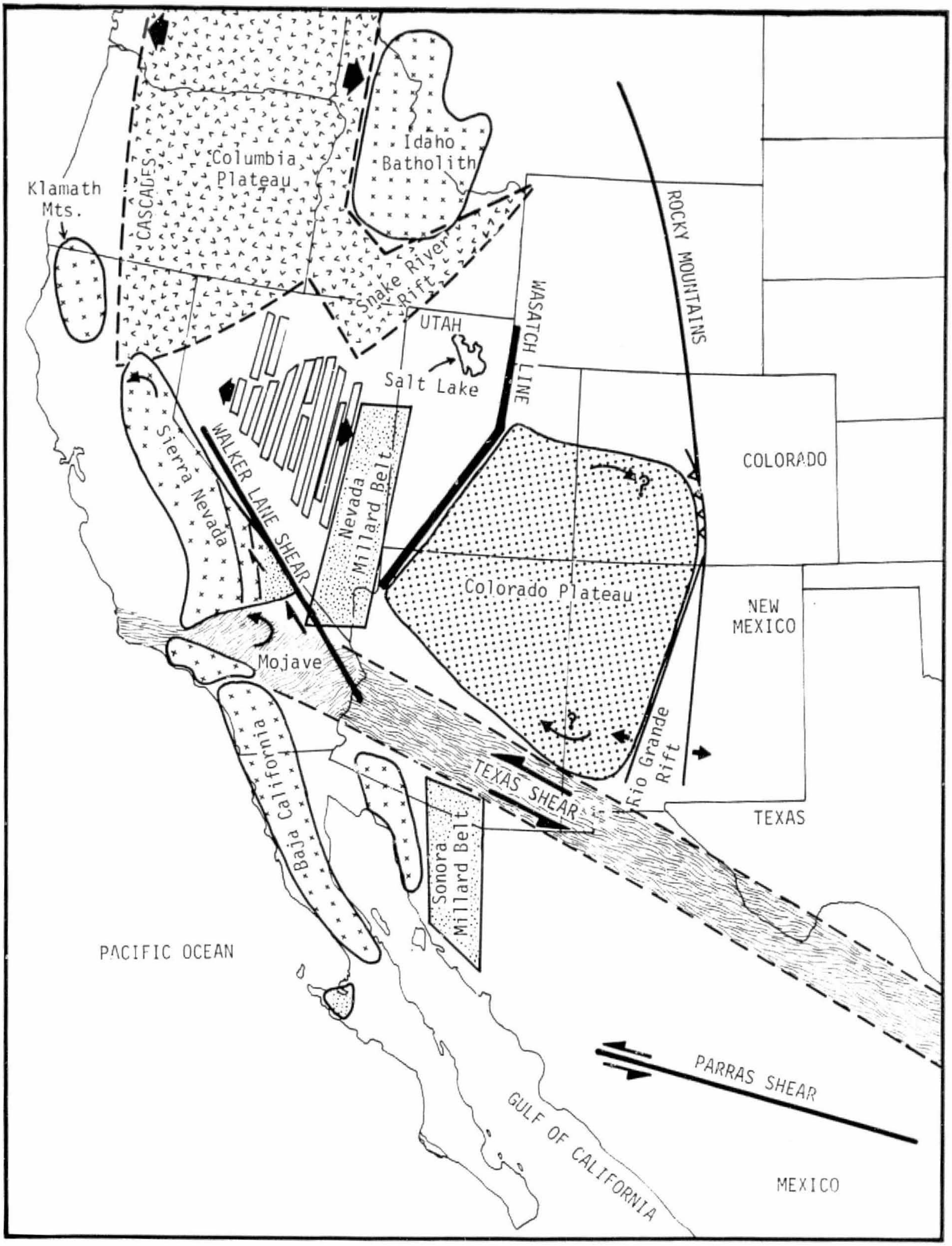


FIGURE 27 PRESENT DISPOSITION OF CRUSTAL BLOCKS IN WESTERN CORDILLERA

generally accepted (Menard, 1960; Cook 1969; Eardley, 1951, and others).

e) Counter-clockwise rotation of the Colorado Plateau approximately 15°. This rotation brings the northwest side of the plateau more in alignment with the Wastach front farther north and straightens out the Wasatch Line "bend" south of Salt Lake.

The present disposition of crustal blocks shown in Figure 27 suggests that since the Late Mesozoic and during the Cenozoic, the following crustal movements have taken place:

Left-lateral Texas Shear: The apparent offset of the Paleozoic Millard Belt in Nevada from its continuation in Sonora, Mexico suggests up to 500 km cummulative displacement across the Texas Shear.

Sierra Nevada - Klamath Mountains: Hamilton and Myers (1966) suggested that the Sierra Nevada has rotated counterclockwise. Rotation around a pole in the Mojave block would result in a considerable translation of the northern Sierra Nevada and Klamath Mountains from a position adjacent to the Idaho Batholith. The rotation could conceivably be in response to the crustal extension and rifting in Nevada and the upwelling of new volcanic crustal material in the Snake River and Columbia Plateau region. Right - lateral shear on northwest faults of the Walker Lane, and oblique rift opening in Death Valley appear to be

consistent with a northwestward movement of the Sierra Nevada block. The rotation may have also affected the Mojave block and with it the orientation of the Garlock fault.

Transverse Ranges, California: Thrusts, left-lateral shear, and counterclockwise rotation may have taken place. This rotation most likely resulted from the northward drift of Baja California and the opening of the Gulf of California.

Colorado Plateau: Clockwise rotation associated with regional uplift is consistent with left - lateral shear along the northwestern side of the Colorado Plateau (Wasatch line). Examples of this shear are the Hurricane Fault Zone (Hamblin, 1965), and the northeast faults offsetting the southern Virgin Mountains, Nevada. A clockwise rotation is also consistent with the opening of the Rio Grande rift and the apparent bending of the Wasatch line south of the Great Salt Lake.

IDENTIFICATION OF RECENT FAULTS

One of the important applications of space photography over tectonically active areas is the identification of geomorphic features associated with recent fault breakage. Several workers (Abdel-Gawad and Tubbesing, 1975; Abdel-Gawad and Silverstein, 1973; Lathram et al, 1973; Bechtold et al, 1973; Carter and Eaton, 1973; Gedney and Van Wormer, 1973 and others) reported that LANDSAT-1 images often show structural lineations where surface fault breaks have not been mapped by conventional techniques. Fault lineations across Quaternary alluvium indicating Holocene breakage are recognizable in LANDSAT-1, Skylab imagery and were earlier observed in Apollo photographs over Pakistan (Abdel-Gawad, 1971). These observations are applicable to assessment problems of seismic hazards. Even where tentative, they contribute to the efficiency of verification by field methods and higher resolution photography. Indeed, the usefulness of space imagery in earthquake hazard assessment is often impaired by the lack of sufficient ground resolution particularly in low contrast areas. In order to address this question, we have compared EREP - S 190 B with U-2 photography and geological maps.

We selected EREP color frame No. SL4-92-350 which covers part of the western Mojave Desert adjacent to the San Bernardino

- San Gabriel Mountains and the San Andreas Fault Zone (Figure 28). The area is seismically active, and the fault pattern is rather well known. For comparison we used the San Bernardino Geologic Map sheet (Rogers, 1967) and the Earthquake Epicenter and Fault Map of California, South Area (Hill et al 1964). The former map was used as the principal reference because it classifies known faults accurately into three categories: mapped faults, faults that are approximately delineated, and concealed faults. The time-stratigraphic and rock units affected by faulting provide information on the relative ages, and on this basis the map shows many faults known to have been recently active. Figure 29 shows the fault pattern compiled from both geologic maps and the EREP photographs. Figure 30 shows a plot of the epicenters of significant earthquakes corresponding to EREP scene SL4-92-350. Numbered arrows in Figure 29, discussed below, identify those segments of faults where geomorphic evidence of faulting was observed. Geologic symbols referred to in the text conform to the San Bernardino geologic map sheet. A discussion of significant observations follows:

1. The West Calico fault shows evidence of recent breakage south of Lava Bed Mts., where it separates Quaternary Continental deposits (Qco) and alluvium (Qal). In addition to the sharp and linear fault contact, breaks in the alluvial fans are noted. It appears to be a wrench fault

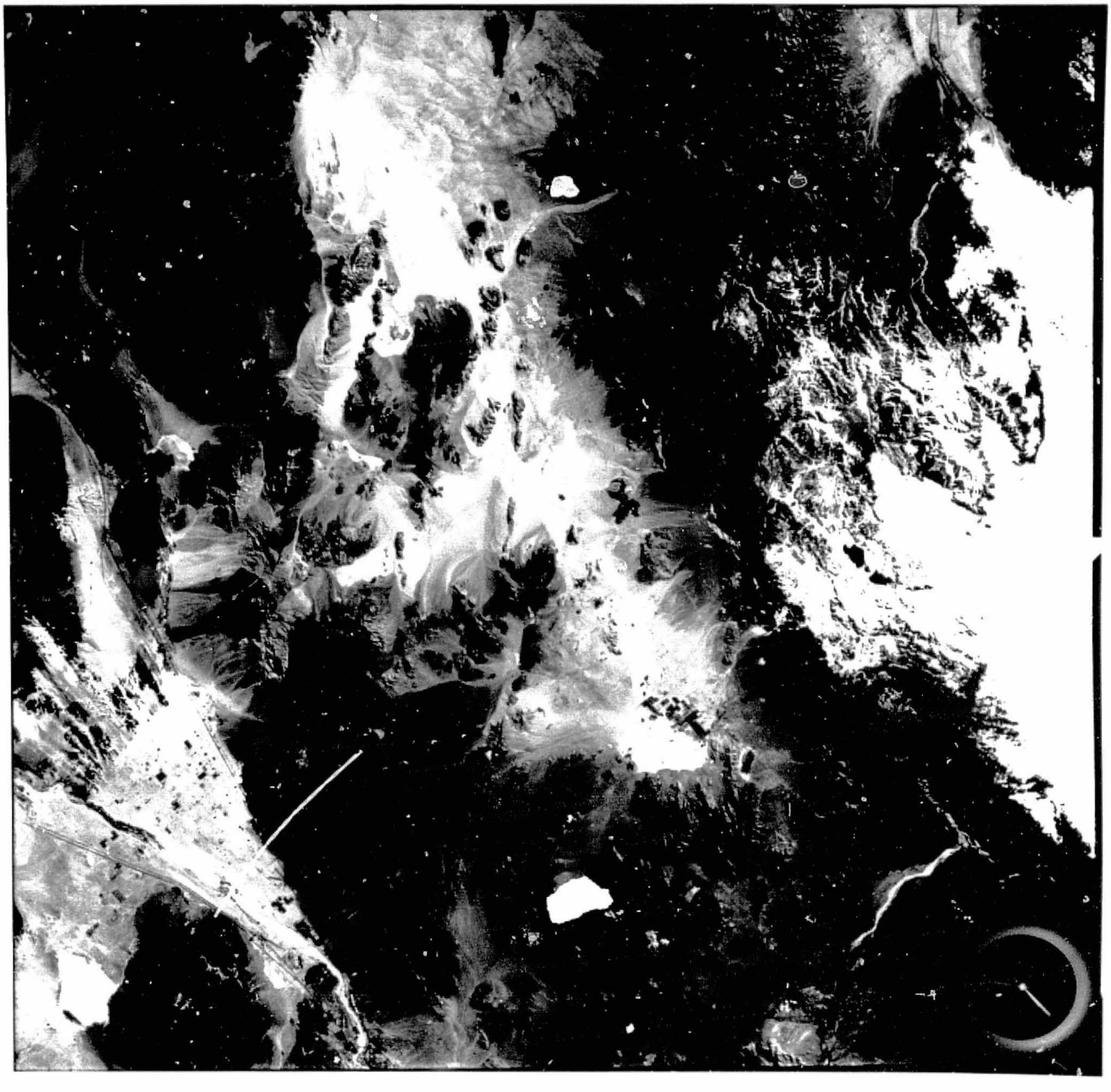
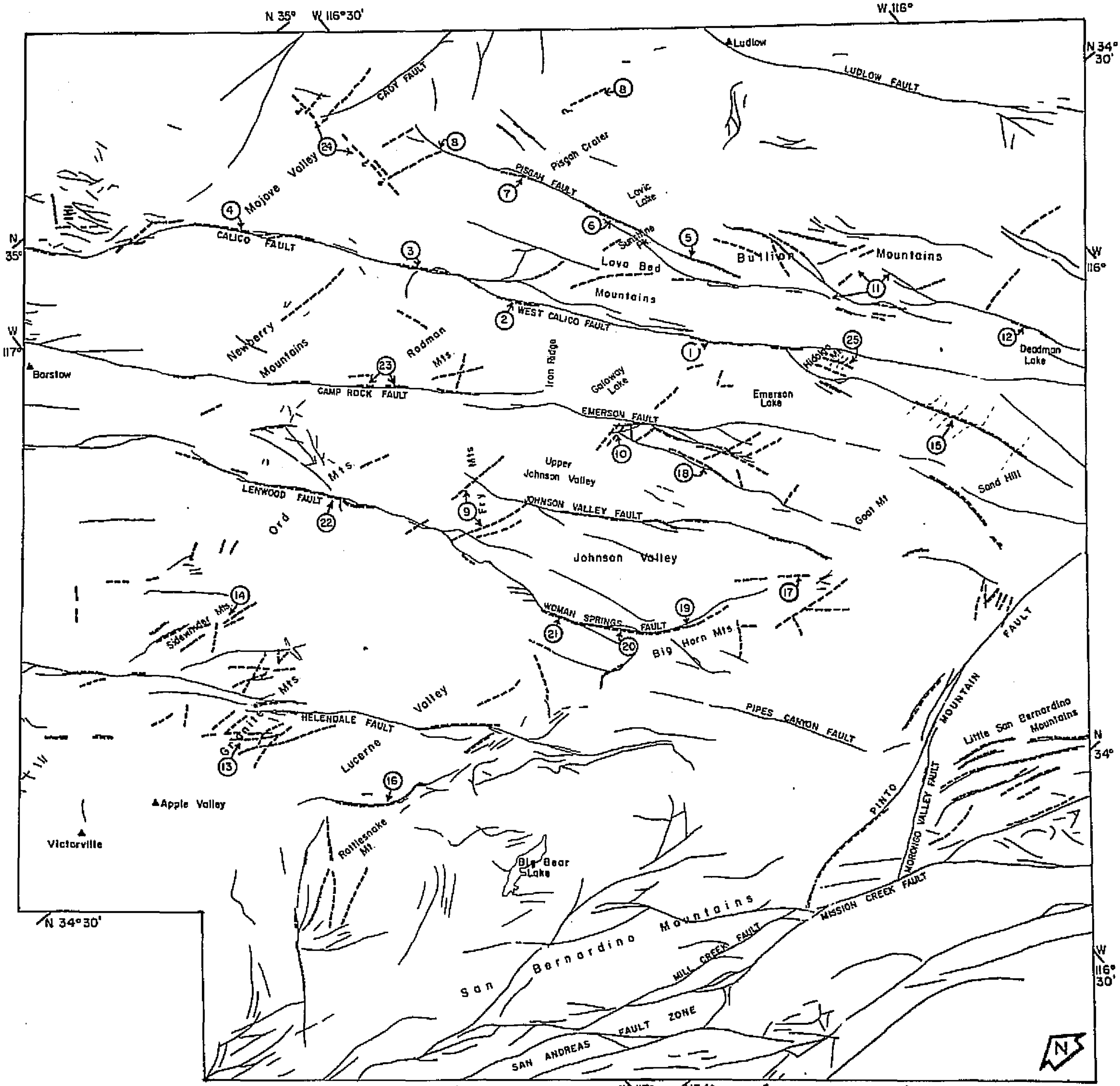


FIGURE 28 EREP SCENE SL4-92-350, WESTERN MOJAVE DESERT



Legend

▲ Town
——— Known Fault
- - - - Fault or Linear seen in Skylab image
(1)→ Fault showing evidence of recent movement; numbers referred to in the text

0 10 20 km.

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FIGURE 29 STRUCTURES OF WESTERN MOJAVE DESERT CORRESPONDING TO EREP SCENE SL4-92-350

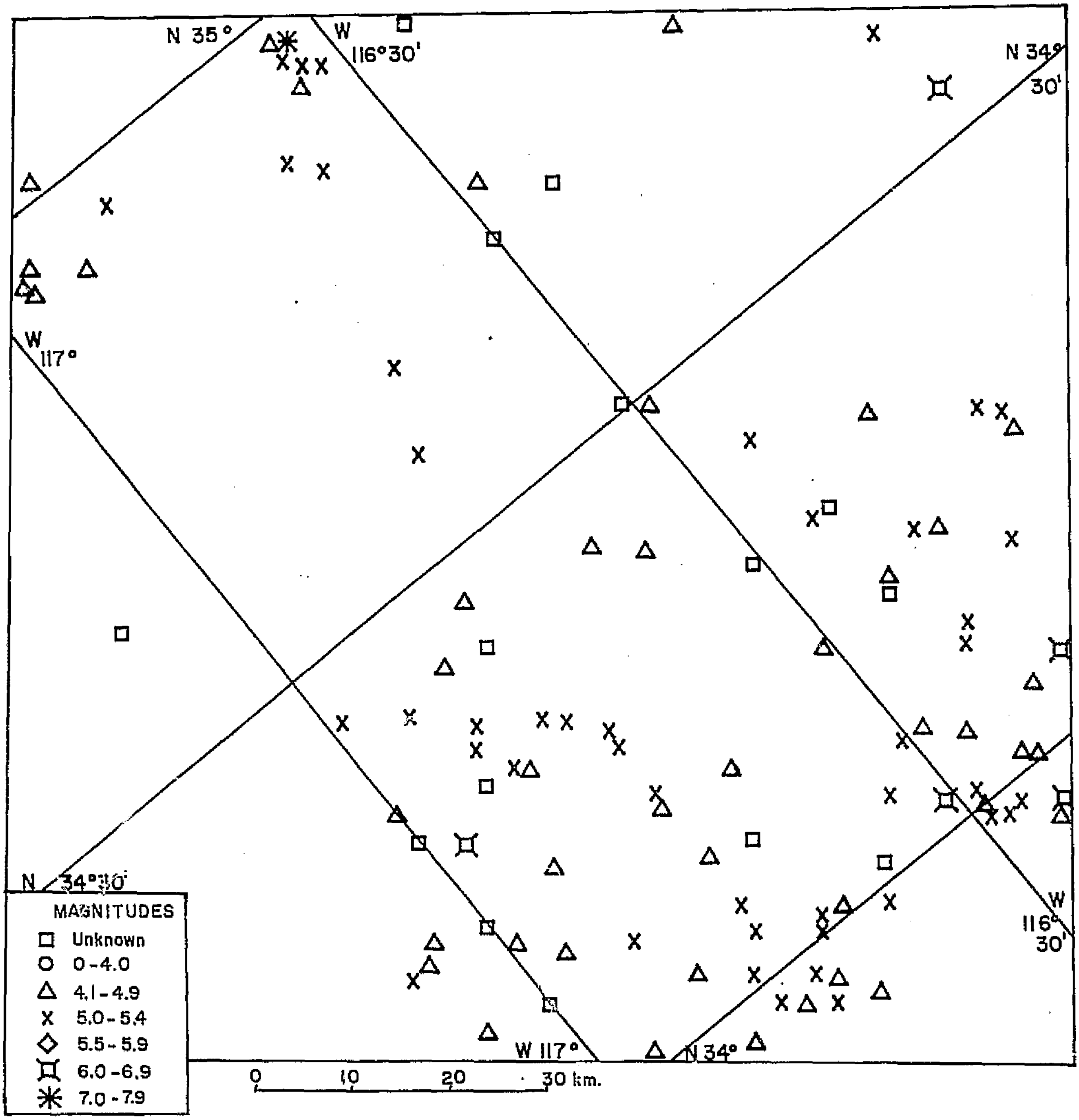


FIGURE 30 EARTHQUAKE EPICENTERS CORRESPONDING TO EREP SCENE SL4-92-350

since uplifted and downfaulted blocks occur on both sides. Where the fault separates Qco and Qal, the northeast side (Qc) appears to have been uplifted in the Holocene.

2. The West Calico fault shows strong surface expression in the Tertiary intrusives (Ti) and granitic rocks northwest of Iron Ridge.

3. The Calico fault shows evidence of right-lateral offset of approximately 15 km affecting Miocene volcanic andesites (Mv) and Miocene continental deposits (Mc) south and north of Highway 40. No evidence of post alluvium breaks was noted.

4. The Calico fault is shown on the geologic map to be concealed where it crosses the Mojave Valley. In the EREP photograph, however, surface expression was evident where the fault passes beneath the alluvium and sand dunes.

5. Pisgah fault shows evidence of post-Pleistocene movement since it cuts Pleistocene basalts near Sunshine Peak and in Bullion Mountain.

6. A fault break is clearly seen in Pleistocene basalt flows just south of Pisgah Crater and west of Lavic Lake.

7. The Pisgah fault cuts Quaternary (Holocene) basalts of the Pisgah crater. Evidence of recent breakage is clear in the EREP photograph and is consistent with the geological map.

8. A set of east-west trending faults not shown on the geological map was inferred from the EREP photograph. Two of the faults are aligned and may be segments of a continuous fault zone parallel to the Cady fault which runs east of Mojave Valley.

9. Several east-west faults were identified mostly through granitic rocks of the Fry Mts. One of these faults passes through an area where Pliocene volcanics, Paleozoic marine strata and alluvium show east-west direction. These and other transverse faults in the Mojave Desert are conjectured to be elements of the Texas Zone.

10. In the mountains between Johnson Valley and Emerson and Galaway Lakes, east trending linears or faults are observed. The faults cut mainly granitic and Mesozoic basic intrusive rocks.

11. In the Bullion Mts., east trending faults appear to offset the mountains and two older faults in a left-lateral sense. Transverse faults separate Miocene volcanics on the north from granites in the south.

12. A known "concealed" fault striking north-northwest shows surface expression near Deadman Lake in an area covered by Quaternary sands. This fault marks a sharp contact between granitic rocks (gr) of Bullion Mountains to the east and the

Quaternary sands of Deadman Lake, and appears to disrupt three small drainage lines descending from the mountains.

13. Several faults are observed in the Granite Mountains north of Lucerne Valley. They trend northwest and east-west across granitic rocks.

14. East trending faults are observed in the Sidewinder Mountains, affecting Mesozoic metavolcanic rocks, granites and adamellites.

15. A known north-northwest fault approximately located on the geologic map is observed across Quaternary non marine sediments west of Deadman Lake and east of Goat Mountain. Here, the drainage pattern is disrupted and right lateral stream deflections are observed.

16. A known fault running between Rattlesnake Mountain and Lucerne Valley is observed cutting across Pleistocene nonmarine sediments (Qc) at the base of the mountains. The fault is also observed in the alluvium and bordering pre-Cenozoic granitic and metamorphic rocks. Post-Pleistocene activity is evident along on this fault.

17. This fault cuts across granitic rocks of the Big Horn Mountains in the northern part of the San Bernardino Mts. and affects Precambrian igneous and metamorphic rocks and, in places, Pleistocene nonmarine sedimentary rocks (Qc).

Recent activity is indicated by the distinct trace across Pleistocene sediments.

18. A known fault trending northwest forms a fault contact between granitic rocks and Quaternary alluvium.

19,20,21. Recent breakage can be inferred along Woman Springs fault southeast of Johnson Valley in three places: where the fault runs between Precambrian gneiss and bordering Pleistocene nonmarine sedimentary rocks (19); where the alluvium appears to be folded, faulted and dissected (20); and where it cuts across Quaternary continental deposits, alluvium, and Pliocene basalts (21).

22. The Lenwood fault has a good surface expression in the Ord Mountains. It is particularly well defined in one area covered by Precambrian schists, granites, Quaternary continental deposits, and alluvium.

23. The Camp Rock fault is well displayed in the Rodman and Newberry Mts. Recent activity is evident in several places where it cuts Quaternary continental deposits, Jura-Trias metavolcanic rocks and alluvium.

24. Bordering the eastern edge of the Mojave Valley are hills composed mostly of Miocene volcanics. Between these hills and the valley there is evidence of a possible north trending linear or fault across quaternary lake deposits (Ql), alluvium, and continental deposits.

25. The fault striking north-northwest in the Hidalgo Mountains cutting across granitic rocks and Quaternary continental deposits is associated with stream offsets or deflections suggesting right- lateral movement. This fault may be the continuation of a known fault which further west, curves around the Hidalgo Mts., (see 15).

Detailed correlation of EREP S-190 B photograph over the western Mojave Desert with geological maps has demonstrated that geomorphic features frequently associated with recent faulting can be recognized with confidence. These features include visible breaks in surficial alluvium and Pleistocene sedimentary and volcanic rocks, stream offsets or deflections, breaks in alluvial fans and fresh rift topography across older rocks.

COMPARISON OF S 190 B and U-2 PHOTOGRAPHS

In this study, we compared one EREP S 190 B frame with U-2 photographs in order to estimate the ground resolution of the EREP photograph and to evaluate the information content on observed faults in comparison with geological maps. Figure 31 shows the location of the U-2 photographs corresponding to EREP scene SL4-92-350.

The EREP color photograph (Figure 28) was taken by the high resolution earth terrain camera (18 inch focal length) over the western part of the Mojave Desert and San Bernardino Mountains, California. This picture was taken on high resolution aerial color (S O 242) film, on December 25, 1973.

The U-2 photographs examined are frames 2755, 2757, and 2759 of Flight 72-112 taken on July 11, 1972 by the RC-10 metric camera (6-inch focal length) on aerochrome infrared (2443) film. These EREP and U-2 pictures were taken under widely different conditions, with dissimilar cameras and film types and, therefore, exact comparisons were neither possible nor intended. Using 9 inch color prints and transparencies, the scale of the U-2 photographs was approximately 5 times larger than the EREP photograph. We utilized a Bauch and Lomb Zoom Transfer Scope to adjust the scale difference. We also made black and white enlargements of a portion of the EREP image comparable in scale

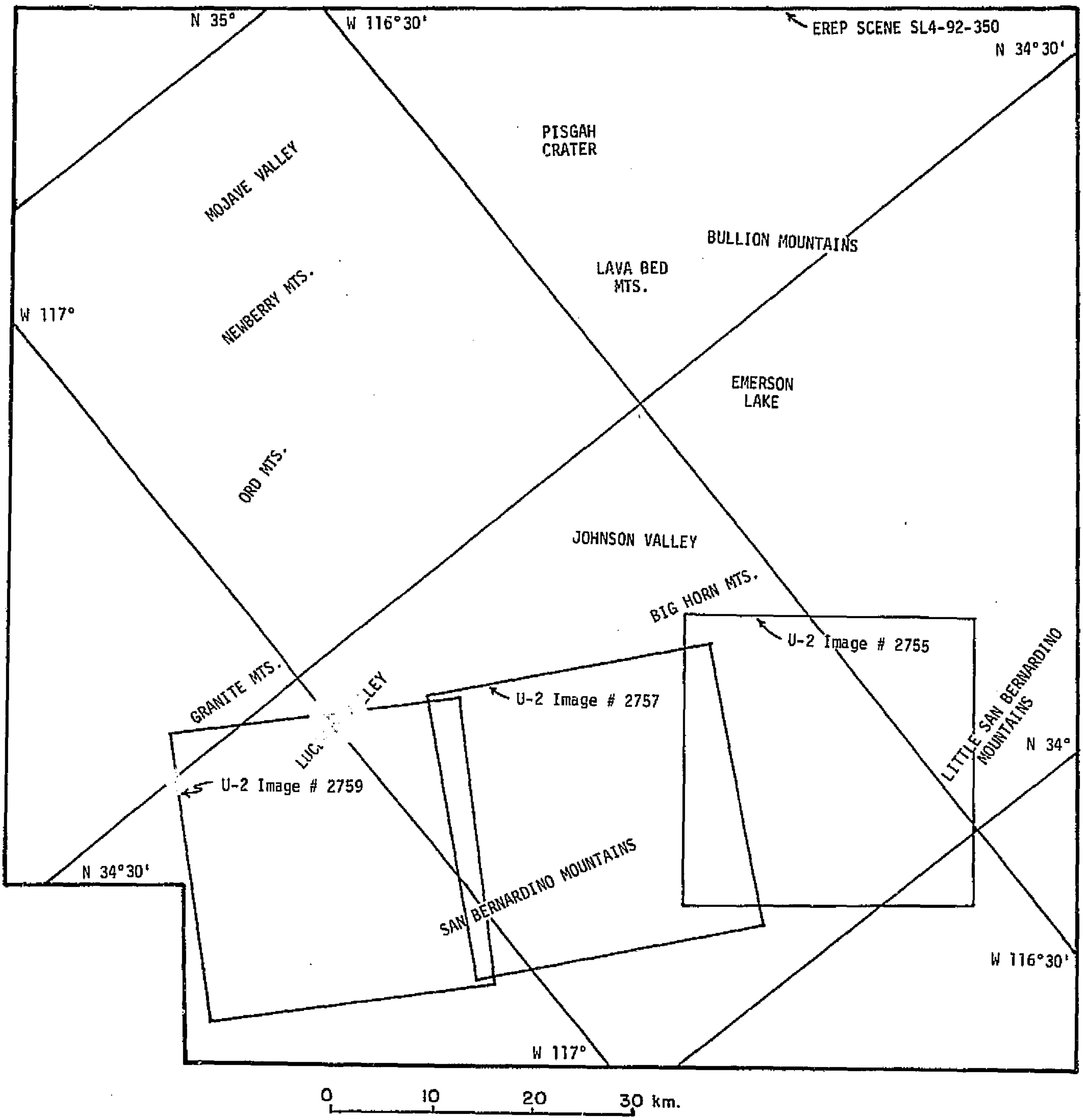


FIGURE 31 LOCATION OF U-2 PHOTOGRAPHS CORRESPONDING TO SCENE SL4-92-350

to a black and white print made from the U-2 picture (figures 32, 33, and 34). A summary of observations on selected structural and cultural features follows:

<u>Roads</u>

Major highways are clearly recognized in both EREP and U-2 photographs. However, minor roads and dirt roads which are clearly visible in U-2 photographs are not always detected in comparable EREP enlargements. Contrast between the road and surrounding terrain appears to be an important factor. An asphalt road 9.3 meters wide near Desert Hot Springs was not visible from surrounding dark alluvium near the foothills of San Bernardino Mountains (3, fig. 33). Also near Desert Hot Springs, the roads in the Mission Lakes Country Club development were not visible in the skylab photo (5, fig. 33). The medium toned asphalt streets within the Country Club were surrounded by desert vegetation (future housing plots) and then the golf course. The streets varied in width from 12.6 meters to 10.35 meters with no dirt borders. A cul-de-sac measuring 20.7 meters across its diameter also did not show up in this area on the EREP photograph. Near Pioneertown and Black Hill, another dark asphalt road 8.4 meters wide (including 0.9 m. of cleared dirt shoulders), could not be seen through heavy brush surroundings and dark alluvium (6, Fig. 33). In Lucerne Valley a dirt road

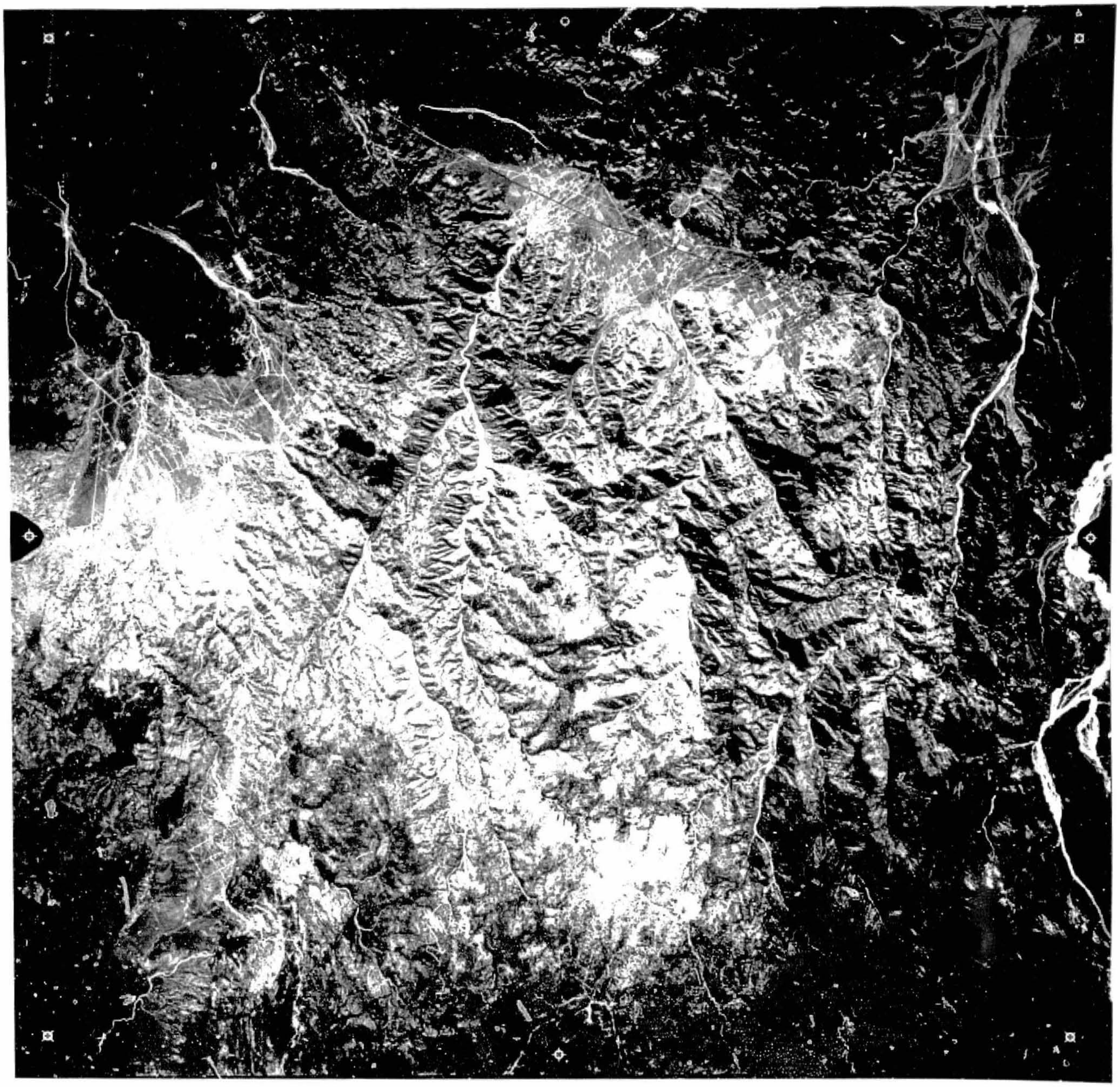
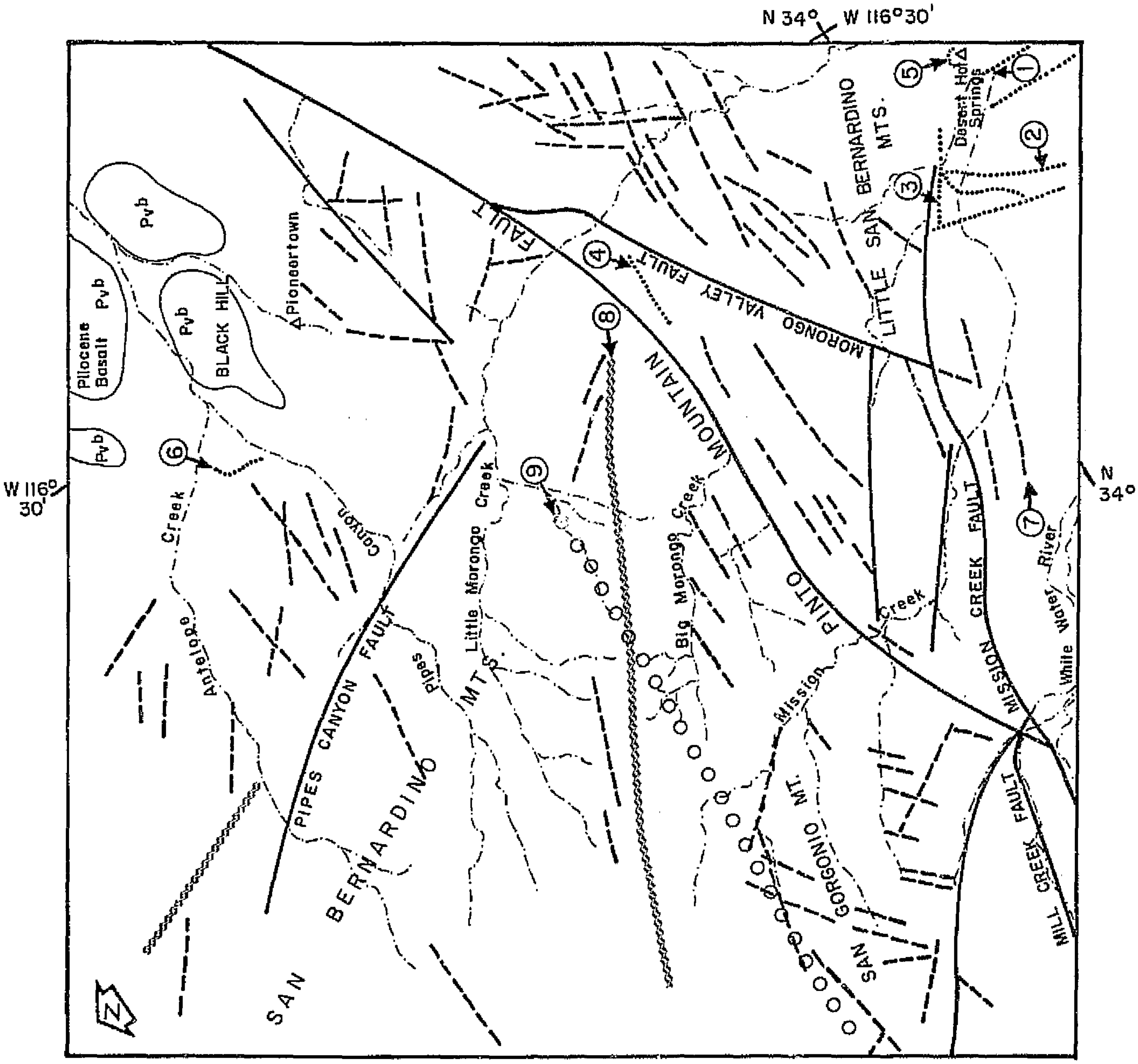


FIGURE 32 U-2 PHOTOGRAPH #2755 OVER SAN BERNARDINO VALLEY AND WESTERN MOJAVE DESERT (FLIGHT 72-112)



Legend

- △ Town
- Drainage
- Known Faults
- Fractures and Linears observed in EREP and U-2 photographs
- ⑧ Linears observed in EREP photograph
- ⑨○○○ Linear observed in U-2 photograph
- ⑦ Recent Fault Scarp in Pleistocene alluvial fan deposits
- Highway

0 5 10 km.

① Dark Asphalt Road; 7.8 meters wide; distinctly visible through light alluvium

② Light Toned Asphalt Road; 8 meters wide; distinctly visible through dark vegetated alluvium

④ Canyon Road; light toned dirt; 6.6 meters wide; faintly visible

③ Dark Toned Asphalt Road; 9.3 meters wide; not visible

⑤ Dark Asphalt Roads; 10 to 12.6 meters wide; not visible: Cul-de-sac width; 20.7 meters; not visible

⑥ Dark Toned Asphalt Road; 8.4 meters wide; not visible

FIGURE 33 FAULT PATTERN CORRESPONDING TO SKYLAB ENLARGEMENT, FIGURE 34

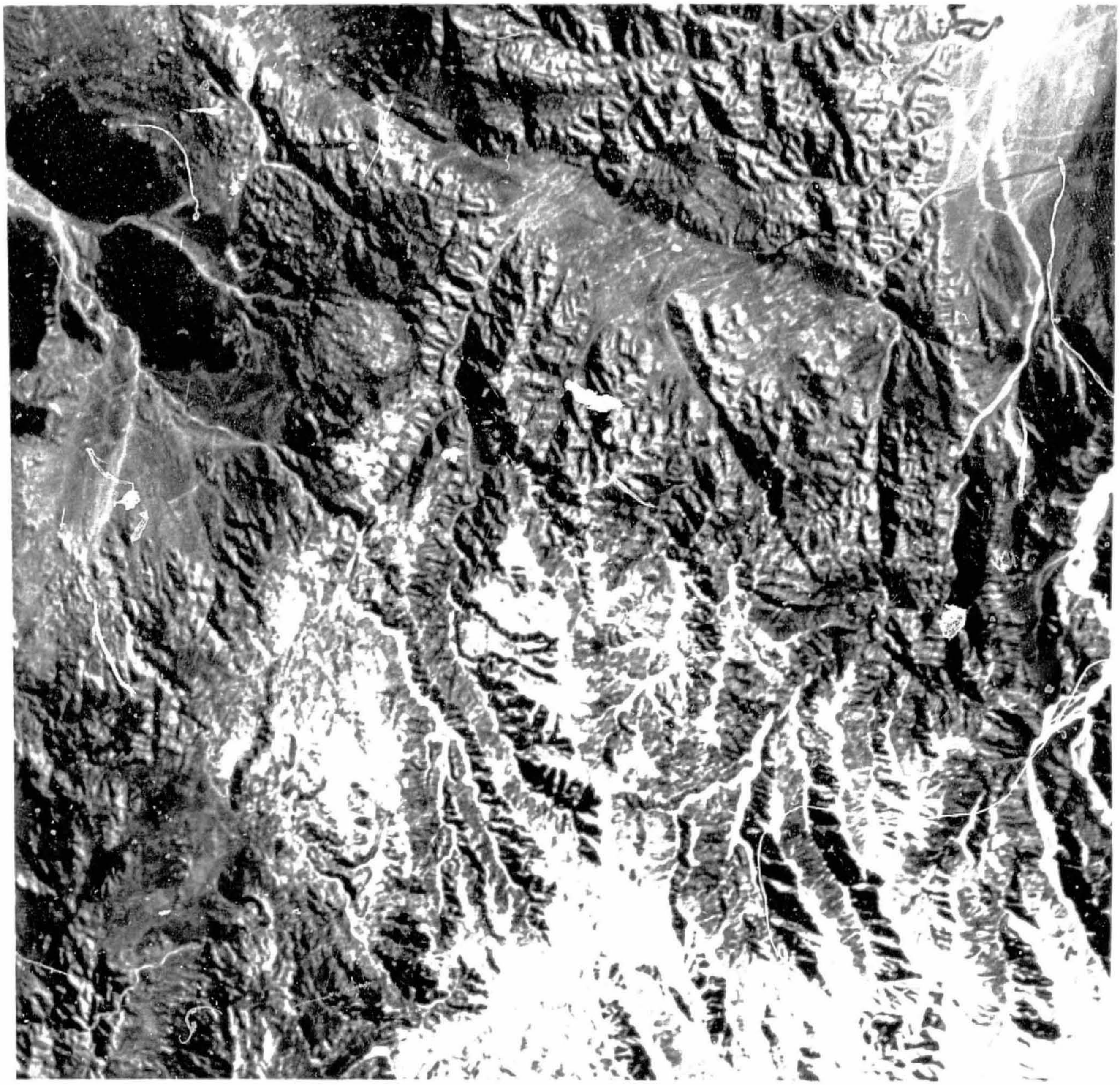


FIGURE 34 ENLARGED PORTION OF EREP SCENE SL4-92-350 CORRESPONDING TO FIGURE 32

measuring 6.9 meters wide was hardly detected in light colored lake deposits with thin vegetation.

On the other hand, comperable and even narrower roads can be detected in high contrast environments. For example, a light paved asphalt road, near Desert Hot Springs, 8 meters wide (including 0.9 m clearing borders) was visible in darker and thickly vegetated terrain (2, fig. 33). Indian Avenue, near Mission Lakes Country Club, is 7.8 meters wide with .9 meter dirt borders (1, fig. 33). It is a medium to dark asphalt road and is very clearly visible as it crosses a gravel stream bed and wash area. In Morongo Valley, Canyon Road is a light paved dirt road measuring 6.6 m and appears clearly through thick vegetation (4, fig. 33). In Flamingo Heights, Butte Street, a light toned dirt road measuring 6 meters wide is faintly visible through fairly vegetated area.

In the San Bernardino mountainous terrain roads are very hard to recognize in Skylab photographic enlargements. Many of these roads are clearly visible in U-2 photographs of the same scale.

Faults, Fractures and Linears

Large known faults such as Pinto Mountain, Mission Creek, Mill Creek, and Pipes Canyon are evident in both U-2 and EREP photographs. Many smaller faults, fractures and linears are also observed. A large linear structure trending east has been

observed only in the EREP photograph (8, Fig. 33). On the other hand, a northeast trending linear appears only in the U-2 photograph (9, Fig. 33). Neither structure was verified in the field. Traces of recent faults are observed in both EREP and U-2 photographs. Arrow No. 7 (Figure 33) points to a recent fault which disrupts the drainage lines and cuts Pleistocene fan deposits exposed in the foothills of San Bernardino Mountains between Mission Creek fault and Whitewater River.

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